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Journal of Sedimentary Petrology

A Publication of the Society of Economic Paleontologists and Mineralogists
a Division of
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NOTICE

Articles submitted for publication to the *Journal of Sedimentary Petrology* should have a prefatory abstract and sufficient postage should be sent by the author to pay the return of the manuscript as it has been found that many articles require more or less revision before publication.

Persons who are not members of the Society of Economic Paleontologists and Mineralogists or are not subscribers to the *Journal of Sedimentary Petrology* but who desire to publish an article in the *Journal,* should have some member of the Society of Economic Paleontologists and Mineralogists or some member of the American Association of Petroleum Geologists sponsor the article. Members of these Societies are given preference in publication.

Among papers to appear in forthcoming issues of the *Journal* are the following:

Petrographic comparison of some loess samples from western Europe with Kansas loess. By A. Swineford and J. C. Frye.

Marine sediments north of Scripps submarine canyon, La Jolla, California. By C. S. Wimberley.

Classification of Permian rocks of western Texas by a versenate method of chemical analysis. By R. G. Guerrero and C. T. Kenner.

Two unusual occurrences of microstylolites. By B. H. Burma and C. M. Riley.

Clastic casts of halite crystal imprints from the Rome formation (Cambrian) of Tennessee. By H. K. Brooks.

Diagnostic heavy minerals in the regolith of Massachusetts. By H. A. Light.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 24, No. 4, PP. 225–234
DECEMBER, 1954

TERMINOLOGY OF LIMESTONE AND RELATED ROCKS: AN INTERIM REPORT

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Yale University, New Haven, Conn.

ABSTRACT

The results of a questionnaire on the terminology of limestone and related rocks indicate where usage is reasonably uniform and where it is sharply divided. From majority usage it is possible to prepare tentative definitions for the following compositional and structural terms: carbonate rock, calcareous (adjective) limestone, dolomite (the rock) or dolostone, dolomitic limestone, calcitic dolomite or dolostone, marl, marlstone, oölite, oöid, coquina, coquinite, and coquinoid (adjective). Usage on terms expressing grain size and on terms expressing genesis is not yet uniform enough to warrant proposing formal definitions, but further debate on these matters should be fruitful, if focused on the distinctions that need to be made among the rocks themselves.

INTRODUCTION

During the '30s, the Committee on Sedimentation of the National Research Council performed a valuable service for sedimentary geology by preparing summaries of the terminology of various groups of sediments and sedimentary rocks, with recommendations (Wentworth and Williams, 1932; Wentworth, 1935; Allen, 1936; Twenhofel, 1937; Tarr, 1938). Unfortunately a summary was never prepared for the rocks composed of calcite and dolomite, whose terminology was then and is still among the least rational. Being much interested in limestone and related rocks, the present writer decided to tackle the task of preparing such a summary. The summaries already presented, though each compiled mainly by one man, owe much of their value to comment and criticism from a large number of interested workers; in an effort to obtain similar comment and criticism for the present summary, the writer prepared in the fall of 1951 a preliminary discussion and questionnaire, which was distributed to interested persons at the Detroit meeting of the Geological Society of America and also by mail. It was not possible to ensure complete coverage of persons working on these rocks, even within the United States; furthermore not everyone who received a questionnaire replied. Nevertheless some 20 replies in all were received, and though statistically this sample may be far from representative, the results are of considerable interest, indicating where agreement is fairly general and where, on the other hand, opinions differ most widely. Accordingly the present paper presents the results of this sampling of opinion, suggests certain definitions that seem to be acceptable to a majority, and points out subjects for further discussion and debate.

This paper would of course have been impossible without the generous cooperation of those who answered the questionnaire: Claude C. Albritton, Jr., R. M. Allen, Ewart M. Baldwin, Virgil E. Barnes, Carl W. Beck, Carl O. Dunbar, Samuel P. Ellison, Jr., Jacob E. Gair, H. R. Gault, August Goldstein, Jr., Marshall Kay, W. D. Keller, Edwin D. McKee, Steven S. Oriel, Francis J. Pettijohn, Duane H. Renc, Richards A. Rowland, Robert R. Shrock, W. H. Twenhofel, F. B. Van Houten, Matt S. Walton, Jr. The writer wishes to thank them all for the time and thought they put into their answers. He also wishes to acknowledge the criticism of Carl Dunbar, Edwin McKee, and Matt Walton on the manuscript of this paper.

The present paper concerns itself with the terminology of those rocks and sediments that are composed dominantly of the minerals calcite and dolomite (including aragonite and the ferroan variety of dolomite, ankerite). Rocks in which magnesite and siderite predominate are not considered, as they are far less common and are not necessarily associated with the calcite-dolomite rocks either in origin or in present distribution.

COMPOSITIONAL TERMS

Limestone

The term limestone, originally a lay word for any rock that can be burnt to produce lime (CaO), has been adopted by geologists and redefined to make it of greater scientific usefulness. Thus the word limestone is not ordinarily used by geologists to refer to coarse metamorphic marbles, though they may burn to as good lime as any unmetamorphosed rock, but it does include many impure rocks that are quite unsuitable for lime or may even burn to a natural cement. In its geological use, limestone has had in general two distinct meanings:

(a) all rocks in which the minerals calcite and/or dolomite are the dominant constituents,

(b) those rocks within group (a) in which calcite predominates over dolomite.

Meaning (a) is the older in geological usage and was dominant in the 19th century, but since then meaning (b) has become more and more common, at least in American usage, as the importance of dolomite-bearing rocks was appreciated.

Of the 22 opinions on this subject received in answer to the questionnaire, 18 favored meaning (b), most of them unequivocally, Of the four dissidents, one strongly favored meaning (a) and the others were dissatisfied with the term limestone for anything but vague field use. Those who did not favor meaning (b) proposed the following terms for these calcite-rich rocks (no one term got two endorsements): calcitic limestone, calcite rock, calcitite, calcitic carbonate, and calcic carbonate.

We may record, therefore, remarkable agreement (for geologists) that limestone means a calcite-rich rock, and the following quantified definition may be suggested:

Limestone—a sedimentary rock containing more than 50 percent of the minerals calcite (plus aragonite) and dolomite (including ankerite), in which calcite (plus aragonite) is more abundant than dolomite.

Calcareous Rocks vs. Carbonate Rocks

If limestone is given the above definition, then a term might be useful to replace it in meaning (a). In the questionnaire, the term calcareous rocks was suggested, but ten respondents stated a preference for carbonate rocks or some similar term, because the term calcareous suggested to them $CaCO_3$ or calcite and hence seemed also to tend toward meaning (b). Probably others would have preferred carbonate rocks also, if the alternative had been presented. One difficulty is that the term carbonate rocks includes not only rocks composed of calcite and dolomite but those made of magnesite and siderite as well. The term calcareous was proposed in the questionnaire in order to exclude the magnesite and siderite rocks; the minerals calcite, aragonite, and dolomite all contain essential $CaCO_3$. As was pointed out in the replies, however, impure dolomite might contain less CaO or $CaCO_3$ than some rocks lying entirely outside the group in question.

Perhaps agreement could be reached on the following definitions:

Carbonate rock—a rock containing more than 50 percent of carbonate minerals.

Calcareous (adjective)—applies to rocks containing appreciable (10 percent?) $CaCO_3$.

Other usages (such as calcareous rocks

in meaning (a)) should be specifically defined in each paper where they are used, for general agreement is not likely at the present time.

Dolomite vs. Dolostone

Of the respondents, 16 accepted the term dolomite for the rock dominated by the mineral dolomite, agreeing to the necessity for careful discrimination between the two uses of the term wherever ambiguity is possible. Dolostone was preferred by four, and four of those who accepted dolomite expressed interest in the term dolostone, though doubtful that it could win general acceptance. On the other hand, four expressed strong objections to dolostone. Other terms proposed were dolomitic limestone, dolomite rock, dolomitite, dololith, and magnesian carbonate.

Dolomite seems widely accepted as a rock name at the moment, but dolostone is a serious challenger. They might be defined as follows:

Dolomite (the rock) or *dolostone*—a sedimentary rock containing more than 50 percent of the minerals calcite (plus aragonite) and dolomite (including ankerite), in which the mineral dolomite is more abundant than calcite.

Further Subdivisions between Limestone and Dolomite (Dolostone)

Various subdivisions of the rocks composed dominantly of the minerals calcite and dolomite have been suggested (e.g., in recent textbooks, Grout 1932; Hatch, Rastall, and Black, 1938; Pirsson and Knopf, 1947; Pettijohn, 1949; Twenhofel, 1950; Krumbein and Sloss, 1951). The following scheme, derived from some of these, was given in the questionnaire as a basis for discussion:

> Limestone (without qualification)—the carbonate mineral is entirely calcite (or may include aragonite). Variety: magnesian limestone—appreciable Mg is present but none of the mineral dolomite.
>
> Dolomitic limestone—both calcite and dolomite are present, the calcite more abundant.[1]
>
> Calcitic dolomite—both calcite and dolomite are present, the dolomite more abundant.
>
> Dolomite (without qualification)—more than 90 percent of the carbonate mineral is dolomite (including ankerite).

With modifications, such a mineralogic scheme was satisfactory to 13, and four more were sympathetic though doubtful that it would be accepted generally. Six suggested that the scheme be made symmetrical by placing the lower limit of dolomite in dolomitic limestone at 10 percent instead of none. Two objected strongly to the proposed definition of the term magnesian limestone, which has often been used in the past for a pure dolomite. One suggested that the percentage boundaries might be 20-50-80 instead of 10-50-90, and another suggested an intermediate category, 40 to 60 percent, to be called dololimestone, on the ground that near equality of the carbonates is more important than slight preponderance of one or the other.

Among those opposed to a scheme of this sort, two thought the finer subdivisions unnecessary, preferring a simple split at 50 percent, two preferred a similar classification but on a purely chemical basis and cited Pettijohn's classification as an example, and one proposed a scheme of subdivisions with limits at 20, 40, 60, and 80 percent and new names for the categories.

The following definitions are therefore suggested:

Dolomitic limestone—limestone in which (the mineral) dolomite is more than 10 percent but less than 50 percent of the combined calcite and dolomite.

[1] In the questionnaire, this read "the dolomite more abundant," but the error was evidently caught by most of the respondents.

Calcitic dolomite or *calcitic dolostone*—dolomite (the rock) or dolostone in which calcite is more than 10 percent but less than 50 percent of the combined calcite and dolomite (the mineral).

Any use of the term magnesian limestone, in view of its other meanings, should be accompanied by a specific definition. If dololimestone or another term for rocks in which the minerals calcite and dolomite are almost equal is needed, it should be specifically defined in each use. If a chemical subdivision is preferred to a mineralogic, this should be explicitly stated, and perhaps a different set of terms should be used.

Marl

The term marl has perhaps most commonly been used

(a) for material consisting of a mixture of clay and calcareous matter, but it has also been used

(b) for calcareous lake deposits, with or without clay, and

(c) for any weakly cohesive clayey rock, as for example the red almost non-calcareous Keuper Marl of the Midlands of England

For meaning (a), quantitative limits have been proposed by Correns (Barth, Correns, and Eskola, 1939, see Pettijohn, 1949, fig. 80) as follows:

	Limits in per cent $CaCO_3$
Kalk	limestone (though Kalk may also include weakly cohesive calcareous material)
	95
mergeliger Kalk	marly limestone
	85
Mergelkalk	marl-limestone
	75
kalkiger Mergel	limey marl
	65
Mergel	marl
	35
toniger Mergel	clayey marl
	25
Mergelton	marl-clay
	15
mergeliger Ton	marly clay
	5
Ton	clay.

Eleven respondents were satisfied with meaning (a), though one specified that "weakly cohesive" be added to the definition. Ten of the eleven accepted Correns' limits of 25 and 75 percent, but one preferred 15 and 85. Two others stated that they seldom or never used the term, but had no objection to meaning (a). Six on the other hand wished to abandon the term entirely, or else to restrict it to use as an indefinite field term. The additional terms marlstone (used by Bradley, 1931, for indurated marl—meaning (a)—in the Green River formation), marlite, and chalk were suggested as germane to the discussion.

The term marl is now being found useful in describing the clayey "chalk" of the Cretaceous of the Great Plains region; hence it seems likely that it will continue to be used by those who deal with such rocks. Others may of course ignore it. As for chalk, for many geologists, perhaps most, it is restricted to material like the well known foraminiferal deposit in the Cretaceous of western Europe and England, but for others it has been widened to include any weakly cohesive relatively fine-grained calcite rock.

A possible scheme taking these terms into account would be:

Weakly cohesive		Thoroughly indurated
Clay		Claystone (or clayrock, see Ingram, 1953)
	25%	
Marl		Marlstone
	75%	
Chalk (in wider sense)		Limestone

and definitions of marl and marlstone would be:

Marl—weakly cohesive sedimentary material consisting dominantly of well mixed argillaceous and calcareous matter, each forming at least a quarter of the mixture.

Marlstone—indurated sedimentary rock consisting dominantly of well mixed argillaceous and calcareous matter, each forming at least a quarter of the mixture.

The words "well mixed" are introduced into the definitions to exclude non-argillaceous chalk and limestone that have abundant clay partings.

Further subdivisions in accordance with Correns' scheme would be available if needed, but should probably be specifically defined in each paper using them. It would probably be premature to define chalk here, but those using the term should make clear how they are using it.

STRUCTURAL TERMS

Oölite, Oölith, Ooid

To quote from the questionnaire: The word oölite, though commonly used in America for the individual spherule, was first proposed and has been consistently used in England for the rock containing the spherules; it means egg-rock. The word oölith has been suggested for the spherules, but its etymology is identical with that of oölite and the two are very likely to be confused; moreover oölith is exactly the German word for the rock. Use of the word ooid (Kalkowsky, 1908) for the individual spherules avoids all these difficulties. Similarly, for the coarser varieties, the terms pisolite and pisoid may be used for rock and individual spherule.

Of those who commented, 10 favored ooid for the spherule and oölite for the rock, another accepted them though he preferred descriptive phrases such as "concretion×mm in diameter" (is an ooid properly a concretion?) and objected to pisoid, and two more accepted ooid but preferred to call the rock oölitic. On the other hand, four preferred to call the rock oölitic and the spherule an oölite, and one saw no difficulty in calling both oölite (like one sheep, 1000 sheep).

Differences of opinion will doubtless continue, but the majority view may be summed up in the following definitions:

Oölite—a sedimentary rock made of spherules that show concentric or radial structure or both. If the spherules are over two mm in diameter, the rock may be called a pisolite.

Ooid—an individual spherule in an oölite. If over two mm in diameter, it may be called a pisoid.

The two o's in these words are to be pronounced separately, each sounding like the o in over, not together like the oo in cool.

Coquina, Coquinite, Coquinoid

Though a few of the respondents rather disliked the words, there seems to be general agreement on the following definitions:

Coquina—a coarsely porous, barely cemented mass of mechanically deposited shells or shell fragments.

Coquinite—a fully cemented mass of mechanically deposited shells or shell fragments.

Coquinoid (adjective)—applies to rock composed largely of shells that have accumulated roughly in place.

The term microcoquina was suggested for finer-grained but otherwise coquina-like material.

GRAIN-SIZE TERMS

In contrast with the well established Udden-Wentworth-Lane scale (Lane, *et al.*, 1947) for describing the grain size of the siliceous fragmental rock series—conglomerate, sandstone, shale—no grade scale has been generally accepted for the carbonate rocks. The texture of carbonate rocks is more like that of igneous rocks than that of sandstone or shale, and the grains of carbonate rocks can rarely be separated and measured individually or by sieves, but must be studied chiefly in the aggregate, in polished or thin section. DeFord (1946) has contributed the most thorough recent discussion of this problem, and he advocates using Alling's grade scale (Alling, 1943; adapted from Cross, Iddings, Pirsson, and Washington, 1906) for the carbonate rocks, partly because it was deliberately proposed for use in thin section rather than on separated grains. The divisions in Alling's scale are geometrically spaced and based on powers of 10, including one

mm. DeFord proposes the following terms for the size classes:

10 mm to 1 mm	megagrained	phaneric
1 mm to 0.1 mm	mesograined	
0.1 mm to 0.01 mm	paurograined	
0.01 mm to 0.001 mm	micrograined	aphanic
0.001 mm down	cryptograined	

Further, each of these classes can be subdivided into four units if need be.

The response on this subject was more diverse than on any other in the questionnaire. Those who expressed a preference were about equally divided between those favoring a scale of the Alling-DeFord type based on powers of ten and those favoring a return to a scale of the Wentworth type based on powers of two; if anything the latter group had the majority. A good example of a Wentworth type scale for carbonate rocks is that of Payne (1942); several of the respondents advocated this or something close to it. DeFord has criticized Payne's terminology, and several of the same criticisms were voiced by respondents to the questionnaire. On the other hand, several respondents objected to DeFord's terms, asking that we use the English language more. One objected to the use of "very" in any set of size terms, as in "very fine-grained." The terms aphanitic and phaneritic, separated roughtly by the limit of visibility of grains, seemed acceptable to practically everyone (but the term porphyritic for limestone with two grain sizes was rejected by everyone who bothered to comment). No one objected to banning the word "dense" in the meanings aphanitic and compact, in view of its proper meaning of high weight per unit volume.

Asked to express a preference between Grabau's terms calcirudyte, calcarenyte, and calcilutyte, and the corresponding English terms lime-conglomerate (and lime-breccia), lime-sandstone, and lime-mudstone, for limestones with clastic texture, six preferred Grabau's terms (mostly with the ending -ite and without his restriction to exogenetic rocks, which would exclude rocks made of shell fragments), whereas 10 preferred the English terms given (some strongly objecting to coined words where English words will do), and two more preferred English terms based on limestone (such as limestone-conglomerate, limestone-sandstone) on the ground that lime alone implies CaO. Further, three objected to all these compound words and urged instead the use of adequately descriptive phrases. Naturally the same general division of opinion extended to the similar terms for the unconsolidated equivalents, though one respondent who preferred Grabau's terms for the consolidated rocks preferred the English terms lime-gravel, lime-sand, and so on, for the unconsolidated materials, as shorter than the phrases calcirudaceous sediment, calcarenaceous sediment, and so on.

Again, agreement appears far away, and for the present everyone will have to understand both sets of terms, for evidently both sets are going to be used. Apparently, the upper and lower limits of calcarenite or lime-sandstone are generally accepted as two mm and 1/16 mm.

GENETIC TERMS

Mechanical, Fragmental, Clastic, Detrital, and Terrigenous

Much limestone is composed not of chemically or biologically deposited precipitates in their original place of deposition but of mechanically transported particles; we say that it is detrital, or clastic, or fragmental, or mechanical. There has been little agreement on the distinctions, if any, between these terms.

The questionnaire distributed suggested that the following categories of limestone need to be distinguished:

A. The limestone is composed of particles that accumulated in their present position one by one, having been brought in by currents or waves, not crystallizing out of solutions where they are found. The particles could be of any origin, including chemical origin; thus they might be chemically formed

aragonite needles as long as their final deposition was not chemical but mechanical.

B. The limestone is composed of particles that are pieces of something pre-existing, such as older limestone, shells, or algal deposits. Particles of purely chemical origin (such as aragonite needles) are excluded.

C. The limestone is composed of particles that are pieces of older limestone. Shells and other organic particles or fragments of local origin are excluded.

Obviously category B includes C and much more besides, and category A includes both B and C and at least some more besides.

As a basis for discussion the questionnaire defined the words in question as follows:

mechanical—category A
fragmental—category B
clastic—same as fragmental
detrital—category C
terrigenous—category C except for material contributed by submarine erosion of older limestone, such as material broken off an active submarine fault block. The suggested meaning of detrital goes back to the usage of Lyell (1840): "matter worn or rubbed off from rock."

Here again, agreement seems discouragingly remote. Seven or eight respondents felt that the proposed distinctions are impractical or of little value, one of them strongly urging that such distinctions be made by describing what is meant instead of looking for single words to do our work for us. One felt that the significant distinctions to be made are: chemical vs. fragmental origin, and source wit[1] in vs. source without the depositional basin. Nine or ten, on the other hand, were sympathetic to the attempted distinction, but some of them pointed out that the terms in question are not strictly comparable, for mechanical refers to process, clastic to texture, and the others to source. Nine accepted (with widely varying degrees of enthusiasm) detrital for category C and fragmental for category B, but more objected to mechanical than were willing to accept it. Of these, several suggested clastic for A, but others doubted the importance of the distinction between A and B or preferred to reserve clastic for texture.

Evidently no final conclusions are warranted from this sampling of opinion but, as a basis for future discussion, the following scheme of definitions applicable to limestones and lime-sediments is suggested:

Process of deposition

Mechanical—the particles of the sediment were brought to their place of final deposition by agents such as water currents, wind currents, or gravity. Examples: shell sand, aragonite-needle mud.

Non-mechanical—the sediment was formed at its place of final deposition, as by chemical precipitation or organic secretion. Examples: travertine, organic reef deposits made of corals and calcareous algae in position of growth.

Texture of deposit

Clastic—the texture shows evidences that the sediment was deposited mechanically, such as cross-stratification or size-sorting of particles.

Non-clastic—the texture shows no such evidences.

Presumably all non-mechanical deposits would show non-clastic texture, but clastic texture might be lacking in mechanical deposits, either because never developed or because destroyed by the recrystrallization so common in limestones.

Source of materials

Fragmental—made up of fragments of other materials, such as shells or older limestone.

Non-fragmental—made up of non-fragments, chiefly newly precipitated matter such as aragonite needles or organic deposits in place.

This distinction is only slightly different form the distinction between mechanical and non-mechanical, but a few mechanical deposits, such as aragonite needles would be non-fragmental. On the other hand, the difference may not be worth maintaining.

Detrital—made up of fragments of pre-existing rocks, not including contemporaneous organic deposits.

Non-detrital—made up of contemporaneously formed materials, whether in position of growth or broken into fragments and transported.

This distinction is very different from any of the preceding, for non-detrital but fragmental, or clastic, or mechanically deposited limestones are a very important fraction of all limestones.

Terrigenous—made up of materials, presumably all detrital, brought from land outside the basin of deposition.

Non-terrigenous—made up of materials produced on the sea floor within the basin of deposition.

Detrital but non-terrigenous materials would be the result of submarine erosion, either erosion of the sort that produces typical intraformational breccias ("edgewise conglomerates"), or erosion of a rising fault scarp on the sea floor. Possible examples of products of the second sort of erosion are the Cow Head breccia and related conglomerates of Newfoundland, and the limestone fragments in the Johns Valley and Haymond formations of Oklahoma and Texas.

Primary and Secondary, as Applied to Dolomite

Sander's important paper on Triassic dolomite in the Tyrol (1936; English translation by E. B. Knopf, 1951) raises the question of the use of the terms primary and secondary with respect to the rock dolomite. Common American usage calls dolomite primary only if the particles were dolomite when first formed, as by direct precipitation from sea water; otherwise they are secondary. Sander, believing that no observable criteria exist for this distinction, calls dolomite primary if the particles were dolomite when they reached their present position in the rock fabric, secondary only if they are replacements of some material that occupied the same position. In view of the great importance of mechanically deposited dolomite, as shown by Sander's work, the distinction between the two usages is real and significant.

Asked to indicate their preferences, nine favored current American usage of the terms, two favored Sander's usage, and one preferred to use primary for all "sedimentary" dolomite, whether produced by direct precipitation or at any time during diagenesis, reserving secondary for post-diagenetic dolomite, such as that produced hydrothermally. Further, two suggested that these terms be not used at all until and unless criteria for them can be found, and that dolomite be described merely as pre-deposition and post-depositional.

Evidently anyone using the terms primary and secondary for dolomite must specify just what he means by them if he is to be understood.

CONCLUDING REMARKS

It should go without saying that the definitions and other recommendations in this paper do not legislate for anybody. It would be folly to suppose that the present writer or anyone else can decide what meaning a given term must have, and it would be improper and unscientific for him to do so if he could. In science, as in any true democracy, any minority has the basic right to dissent, and to endeavor, by rational argument, to persuade the majority to alter its views. But there is another side to the coin. The privilege of unlimited dissent and disagreement carries with it the obligation to submit the dissenting view to rational scrutiny as searching as that to

which the dissenter believes he is subjecting the orthodox view. With respect to terminology, the scientist who exercises the undeniable right to his own private usage must not forget the equally undeniable danger that as a result his papers may be completely misunderstood or, worse still, ignored, and that he may be remembered by future scientists not as a useful contributor to the common task but as a curious eccentric. How to strike the balance between slavish aping of the majority view of the moment and obstinate persistence in unfruitful opposition must be decided by each individual.

The purpose of the present paper then is not to settle matters of limestone terminology once and for all, but simply to indicate where a settled majority view exists and where it is absent. Where it appears to exist, the definitions offered here are intended to codify the majority usage; doubtless these will require further modification and refinement before they are generally accepted, and criticism is hereby solicited. Those who disagree with them have the right to reject them completely, but they have also the duty to make this rejection (with the reasons for it) and their own counter-definitions crystal clear. Where a majority view is absent, some basis for discussion is here offered, in the hope of focusing the debate on significant distinctions that need to be made among the rocks themselves, whatever terms are employed to make them. And here all of us have the duty to define our terms with special care and clarity, in order to bring out differences in terminology explicitly, lest concealed misunderstandings on terms vitiate our discussions of the real and much more important distinctions in the rocks themselves.

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FIGS. 1–3, PLS., I–IV, DECEMBER, 1954

MIOCENE ORTHOQUARTZITE FROM NEW JERSEY

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ABSTRACT

An orthoquartzite occurring in the Miocene Kirkwood formation of New Jersey is cemented by opal and chalcedony and contains fossils that are replaced by opal, chalcedony, and quartz. The rock is further characterized by its variable cementation, fine to medium sand size, light color, good sorting, and heavy mineral fraction which is similar to that of the unconsolidated portions of the Kirkwood and Cohansey formations. Evidence is presented to support the theory advocated by W. A. Tarr (1926) that precipitated silica will in time pass from opal to chalcedony to quartz. It is suggested that the silica replaced the original shell material and then was precipitated between the grains as a cement after the sand was shifted by emergence from a neritic to a lagoonal environment.

INTRODUCTION AND ACKNOWLEDGMENTS

The orthoquartzite described in this paper occurs as small bodies in the Miocene Kirkwood formation of southern New Jersey. It is believed to be in place along Cohansey Creek near Fairton and Greenwich, Cumberland County, and to occur as boulders, derived from slope wash, at or near the surface 1½ miles south of Swedesboro, Gloucester County, New Jersey. The rock is a highly indurated to friable, fine- to medium-grained, light colored orthoquartzite cemented by opal and chalcedony and containing fossils replaced by opal, chalcedony, and quartz. This type of rock is rare in the Atlantic Coastal Plain and hitherto has not been described in detail.

Salisbury and Knapp (1916) reported that Miocene quartzite boulders occur in the Bridgeton formation (Quaternary) south and southwest of Swedesboro, and that similar boulders were found as far east and south as Hammonton, Folsom, and Tuckahoe, New Jersey. Horace G. Richards (1935) described the locality near Fairton, Cumberland County, and identified fossil mollusks imbedded in quartzite slabs that had been dredged from Cohansey Creek. He described the quartzite as cemented by silica and correlated the fauna with that of the Shiloh "marl" (Kirkwood). Richards and Harbison (1942) found the quartzite only in the vicinity of Cohansey Creek near Greenwich, Fairton, and Bridgeton. C. F. Kier Jr. (1949) described the use and distribution of quartzite artifacts fashioned by aborigines from quarry sites in the Kirkwood formation. He stated that usually fossils in the rock were replaced by chalcedony. Recently W. H. Hayes (1953) described the locality at the Ewing Farm and stated that the quartzite was cemented by silica and that the fossils were replaced by chalcedony. He said that "without doubt the quartzite was formed by silica in solution having permeated the sand while it was stationary, and after there had been deposited in it numerous shells of bivalves . . . "

The present investigation was completed in 1953 at Rutgers University under the guidance of Professor James H. C. Martens. Deep appreciation is extended to Professor Martens for his unfailing interest, and to Professors H. Johnson and A. S. Wilkerson for their helpful suggestions in the preparation of this paper. The writer is also indebted to Dr. Horace G. Richards of the Academy of Natural Sciences of Philadelphia for his identification of fossils.

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FIELD RELATIONS

The Kirkwood formation is exposed in a northeast-southwest belt across the southern portion of the State (fig. 1), and dips 11 to 25 feet per mile to the southeast (Johnson and Richards, 1952). The formation thickens down dip from its

FIG. 1.—Index map of the outcrop area of the Kirkwood formation in New Jersey.

feather edge to a total of more than 600 feet along the Atlantic Coast. Along its outcrop the Kirkwood formation consists predominantly of light colored, fine, micaceous, quartz sands. Locally lithofacies of drab-colored clay, clayey sand, and calcareous sand occur. The orthoquartzite is found at three separate localities in the southwestern feather edge of the formation.

An outcrop of the orthoquartzite can be seen at low tide along the right bank of Mill Creek, a branch of Cohansey Creek, on the property of the Fairview Farms, Fairton, Cumberland County. This is approximately 100 yards from the tide gate on the road that separates Mill Creek from Clark's Pond. Many angular slabs of the rock that evidently were dredged from the channel are found along the bank. At extreme low tide an outcrop some 30 feet long and two to three feet thick is exposed. The limits of the rock mass are obscured by river mud, but the rock is believed to be in place for it is underlain by clean quartz sand not contaminated by the river mud. Three varieties of the orthoquartzite are observed at this locality. They are: (a) light-gray to pinkish-tan, highly indurated, fine-grained orthoquartzite that is characterized by breakage across the grains; (b) gray to light-brown, sugary textured, quartzitic sandstone marked by iron-oxide stains and variable degrees of cementation; and (c) fossiliferous varieties of each of the above. There is every gradation between the types throughout the rock mass and in hand specimens.

At Greenwich, Cumberland County, in the southwest part of the Ewing farm are countless angular pebbles and cobbles of a gray- to light-brown, highly indurated, fossiliferous, fine-grained orthoquartzite. Also, at Greenwich Pier, less than one-quarter mile from the Ewing farm, there is reported to have been a quarry in the orthoquartzite. This quarry is now depleted, but rocks probably originating there were examined and found similar in every way to those at Fairton and the Ewing farm.

Within the area two miles southwest and southeast of Swedesboro, Gloucester County, gray- to light-brown, iron-oxide stained, variably indurated, fine-grained, angular orthoquartzite boulders occur at the surface. These resemble the rocks from Fairton and Greenwich except that those at Swedesboro are unfossiliferous and contain peculiar weathered-out cavities (possibly a related phenomenon). Large blocks of the rock can be seen in place at the contact between the Horners town "marl" (Eocene) and the overlying

Kirkwood as exposed in the northward flowing stream approximately 1½ miles miles southeast of Swedesboro (M. E. Johnson, personal communication, 1952). The occurrence of the orthoquartzite at Swedesboro suggests that the boulders are the result of local cementation and that they were derived by slope wash from the basal part of the Kirkwood formation.

In the "marl" pits three to four miles northwest of Shiloh, Cumberland County, pebble-size, iron-oxide stained, loosely consolidated aggregates of sand and mollusk shell fragments occur that lie in the upper part of the Kirkwood formation. Samples were obtained with a post-hole auger from approximately nine to 12 feet below the surface. The shell fragments are completely replaced by opal and chalcedony which also serve to cement the detrital grains adjacent to the shell. The degree of cementation decreases rapidly away from the shell fragments. The coalescing of numerous cemented "spheres," with a shell as the nucleus, serves to consolidate the aggregate. The aggregates are probably authigenic as they are too loosely indurated to have withstood transportation. It is suggested that these sand and shell aggregates represent the incipient development of the chalcedonic and opaliferous orthoquartzites of the Kirkwood formation.

LABORATORY DESCRIPTION

Cement

The nature of the cement in the orthoquartzite was determined by study of thin sections and crushed samples under the petrographic microscope. In fragments of the crushed sample enough cement adhered to the grains so that the cementing materials were easily identified as opal and chalcedony by their optical properties. These two forms of silica are closely associated and their relationships indicate a common origin. The opal always occurs adjacent to the detrital grains either in the form of numerous layers or films that envelope the grains or as a massive binding agent. Occasionally the opal retains its original globular form in which case it is concentrically layered and radially fractured. Locally chalcedony is observed to form the first layer adjacent to the grains, successively rimmed by the opal layers. More commonly, however, the chalcedony occurs as microfibrous, fan-shaped aggregates that are restricted to the centers of the interstitial openings where initially there was sufficient room for them to crystallize (pl. I).

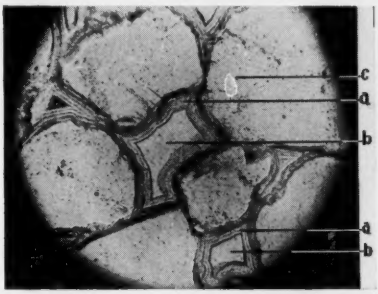

PLATE I.—Opal and chalcedony cement in Kirkwood orthoquartzite from the Ewing Farm, Greenwich. a. Layered nature of opal; b. Chalcedony; c. Quartz grains. Lower nicol, ×144.

In a few samples chalcedony with microscopic inclusions of opal serves as the cement. The chalcedony appears as the same microfibrous material described above except that when viewed under crossed nicols of the petrographic microscope it forms a mosaic of gray and black interpenetrating fans. With high magnifications the opal can be seen as rounded inclusions in the chalcedony (pl. II).

Relative amounts of grains, cement, and holes, as shown in table 1, were obtained by measuring their respective intercepts in homogeneous thin sections by the Rosiwal method of analysis. The length of the traverses across each slide averaged more than 600 times the average grain size. A portion of the percent-

age attributed to holes may be counted in with that for the grains, for many of the holes measured resulted during the preparation of the thin section when grains fell out of their positions. The proportion of cement is believed to be directly related to the original porosity of the unconsolidated sands.

TABLE 1

Samples	Cement	Grains	Holes
	(percent by volume)		
A	31	69	—
B	34	66	—
C	43	48	9
D	46	52	2
E	38	56	6
F	44	53	3
G	38	57	6
H	42	55	3
Average	40	57	4

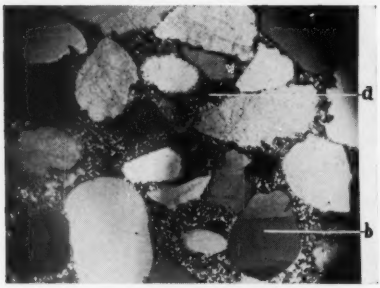

PLATE II.—Kirkwood orthoquartzite from the Ewing farm cemented by chalcedony with minute inclusions of opal. a. chalcedony mosaic; b. quartz grains. Crossed nicols, ×66.

Fossils

Fossils have been collected from the orthoquartzite at Fairton and Greenwich. Species of oysters, barnacles, gastropods, and pectens are present, and these represent a shallow water, neritic assemblage. The fossils are correlated with the fauna at Shiloh, New Jersey, and are equivalent to that of the Calvert formation, Maryland (Richards and Harbison, 1942). Dr. H. G. Richards identified the following forms:

At Fairton (1935):

Eucrassatella melina (Conrad)
Nucula proxima (Say)
Ostrea virginica (Gmelin)
Astarte sp.
Turritella cumberlandia (Conrad)
Discina lugubris (Conrad)
Balanus withersi (Pilsbry)

At Greenwich (personal communication, 1953):

Eucrassatella melina (Conrad)
Ostrea percrassa (Conrad)
Pecten madisonius (Say)
Turritella cumberlandia (Conrad)
Balanus sp.

The original shell material of the fossils is replaced completely by combinations of opal, chalcedony, and quartz so that although the shells are broken, their plications, growth rings, and features of ornamentation are in most samples well preserved.

The relationships of the mineral replacement in the fossils were studied in thin sections. Within the fossil outline opal appears as yellowish-gray, isotropic, coalesced, spherical globules that at the borders of the mass present semi-circular forms inward. Opal is always found at the outer edges of the fossil outline, and may partially or completely fill in the outline. When opal does not completely fill the fossil chalcedony is always found. Frequently concentrically layered opal globules occur as peninsulas, or islands surrounded by chalcedony. The chalcedony appears as fan-like aggregates radiating from centers throughout the mass. Under a single nicol the concentric, mammillary structure of the fans can be seen. When opal and chalcedony do not completely fill the space within the fossil euhedral to subhedral quartz crystals and some void spaces are observed. The possibility of these quartz crystals being formed by circulating solution—that is,

a cavity filling type of occurrence—is precluded by the fact that other voids in the rocks do not contain the quartz crystals. Quartz is found only adjacent to the chalcedony which always separates the quartz from the opal. The replacement was evidently volume for volume (pl. III, IV).

The occurrence of the three forms of silica in this manner suggests that once the siliceous precipitate had accumulated between the grains and replaced the shells, changes took place within the mass that in time promoted the formation of opal, chalcedony, and quartz. Tarr (1926) in conjunction with his theories on the origin of flint and chert, visualized the following sequence of events as an explanation for the associations of opal, chalcedony, and quartz:

"... The most important change brought about after burial of a siliceous mass is the loss of water through dehydration.... The loss of water proceeds slowly ... until finally the gel is a supersaturated super-cooled liquid. When this state is reached the silica crystallizes instantly as cryptocrystalline chalcedony. The reason for regarding the gel as a supersaturated liquid is that under such conditions crystallization, once induced, takes place immediately throughout the entire nodule or mass, thus giving rise to an infinite number of points of crystallization. If all the water in the gel at the time of crystallization is not immediately eliminated, those portions where the water is segregated will slowly crystallize into more fibrous chalcedony, or, if there is more space, solution, and time available quartz will be the result."

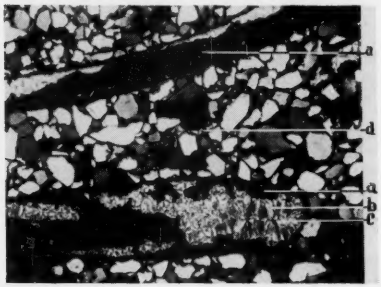

PLATE III.—Kirkwood orthoquartzite from Fairton illustrates replaced shells surrounded by quartz grains cemented by opal and chalcedony. a. replaced shell—massive opal; b. fibrous chalcedony within shell; c. subhedral quartz crystals; d. opal and chalcedony cement. Crossed nicols, ×26.

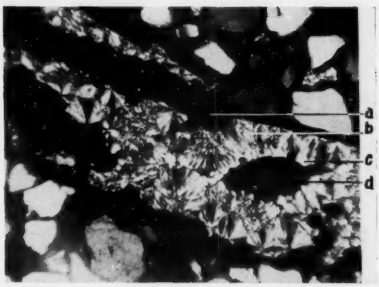

PLATE IV.—Replaced fossil shell in Kirkwood orthoquartzite from Fairton illustrates the following: a. opal; b. fibrous chalcedony; c. subhedral quartz crystals; d. void. Crossed nicols, ×66.

DETRITAL GRAINS

The nature of the detrital grains was studied in thin section and crushed samples. Representative samples of the orthoquartzite were crushed in a heavy iron mortar. Because of excessive breakage of the quartz grains in the highly indurated samples these were used only for heavy mineral analyses. The friable samples were easily disaggregated and these were used for study of both grain size and heavy minerals. Sieve tests were made with Tyler Standard Screens and a Ro-Tap shaker. Heavy mineral separations were made in bromoform (2.85) and split portions of the bulk heavy fraction were mounted in aroclor (RI.-1.66) for analysis.

Quartz grains comprise approximately 97 to 99 percent of the detrital elements, while feldspars, heavy minerals, and undetermined grains now replaced by opal also occur in small numbers. The heavy

Heavy Mineral Data

Sample	Percent by Number							
	B_g	D_f	E_f	G_f	I_s	II_s	III_s	IV_s
opaques	55	66	68	70	84	78	85	30
staurolite	20	12	14	10	2	2	3	—
zircon	4	7	8	12	7	13	8	51
tourmaline	5	4	4	3	2	3	1	12
rutile	2	2	1	2	3	2	2	6
sillimanite	2	3	1	1	Tr	Tr	Tr	—
kyanite	4	1	1	1	Tr	Tr	Tr	—
andalusite	1	2	1	Tr	—	Tr	—	Tr
corundum	4	2	Tr	1	—	—	—	—
garnet	2	Tr	Tr	Tr	—	—	—	—
chloritoid	1	Tr	Tr	Tr	—	—	Tr	Tr
opaques								
black	61	62	64	62	5	3	12	1
brown	20	23	21	22	51	24	59	89
white	19	15	17	16	44	73	29	10
Percent by weight of heavy fraction	0.2	0.2	0.4	0.3	1.4	0.7	1.6	0.1

FIG. 2.—B_g—sample B from Greenwich, D_f—sample D from Fairton, I_s—sample I from Swedesboro. Tr—trace (less than one percent)

mineral fraction averages 0.9 percent by weight. The following varieties of quartz are present: (a) grains with numerous inclusions of liquid and gas (normal igneous variety), (b) grains with tourmaline and zircon inclusions, (c) grains of quartzitic aggregates, (d) grains with quartz overgrowths, edges rounded, (e) and grains anomalously biaxial. The quartz in the Kirkwood formation can thus be traced to both igneous and metamorphic sources as well as those of a previous sedimentary cycle (Krynine, 1940).

Heavy mineral data are presented in figure 2. The following minerals are present in decreasing order of abundance: opaques, staurolite, zircon, tourmaline, rutile, sillimanite, kyanite, andalusite, corundum, garnet, and chloritoid. These represent a rather stable assemblage. The opaque grains form 55 to 85 percent by number of the heavy fraction. Although not investigated in detail they are believed to show all stages in the alteration of black, metallic ilmenite to white aggregates of leucoxene. The heavy mineral fraction found in the Kirkwood orthoquartzite is similar to that of the unconsolidated portions of the Kirkwood and Cohansey formations.

Figure 3 represents the results of size analyses. The samples shown are typical of the orthoquartzite in general. Data derived from the curves are shown below:

Sample	*Median*	*Sorting Coefficient*
A	0.22	1.37
B	0.18	1.27

Plates II and III show the angular to rounded nature of the grains, and also the complete lack of compaction illustrated in these sections and in all others examined.

ORIGIN

The following mode of origin is suggested for the orthoquartzite. Data accumulated on the heavy minerals, quartz grains, fauna, size and sorting, and field relations suggest that the Kirkwood sands were deposited in shallow water,

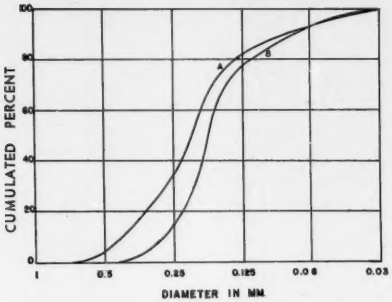

FIG. 3.—Size analyses of the Kirkwood orthoquartzite from Fairton, Cumberland County, New Jersey.

neritic environments, and that they were derived from older sedimentary formations and from metamorphic-igneous sources. A source area ideally suited is found to the west of the present outcrop of the Kirkwood formation in southern New Jersey. This region is comprised of the older sediments of the Coastal Plain, the Glenarm metamorphic-igneous complex, and the Lower Paleozoic sedimentary rocks. This interpretation is in accord with the findings of Dryden and Dryden (1940).

Study of the occurrences of opal, chalcedony, and quartz in the replaced fossils, in the cement of the orthoquartzite, and in the shell and sand aggregates from Shiloh suggest a definite sequence of events. First, in order to account for the sporadic occurrence of the orthoquartzite and the necessary concentrations of silica and electrolytes for the precipitation of silica, a shift from the neritic depositional site of the sands to a lagoonal or estuarine environment is postulated. Slight emergence, like that recorded at the close of Kirkwood time, could have affected this change. Second, if the shell and sand aggregates from Shiloh are reliable criteria, then the replacement of the shells took place before the precipitation of the silica between the grains as a cement. It is believed that in the immediate vicinity of the calcareous fossils the increased concentration of calcium ion would foster the precipitation of the silica gel and facilitate the replacement of the shell. Third, the silica would be emplaced between the grains as the critical balance between electrolytes and silica was reached. Fourth, once deposited, changes within the opaline gel would account for the opal, chalcedony, and quartz associations described above.

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FIGS. 1–3, DECEMBER, 1954

QUANTITATIVE ESTIMATIONS OF CLAY MINERALS BY DIFFRACTION METHODS

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ABSTRACT

The clay mineral components of Recent sediments and soil materials exhibit structural attributes unlike those of many so-called standard clay materials. The interpretation and significance of some of these is discussed in detail. Factors involved in analyzing these materials quantitatively are considered and a general procedure outlined.

INTRODUCTION

The identification and estimation of relative abundance of the clay minerals in complex mixtures when the constituents are of a relatively low order of crystallinity is a matter of considerable difficulty. In studies of Recent sediments and soil materials, the authors have had considerable experience with such complex mixtures, and the present paper presents a procedure for their analysis which has given satisfactory data and is not unreasonably time consuming.

GENERAL PROCEDURE

The procedure will be illustrated by examples of clay mineral analyses of Recent sediments from the Gulf of Mexico off the Texas coast. In these samples, the minus-two-micron fraction as obtained by wet fractionation contains substantially all the clay mineral component, and relatively little nonclay mineral material. Analytical data for the clay mineral analyses are obtained for the minus-two-micron fraction. Fractionation without the use of a chemical dispersing agent is possible if the soluble salts are first washed from the sample with distilled water. Care is taken so that at no time is the sample or size fraction subjected to a temperature substantially above room temperature.

Differential thermal data have proven of little value in the study of such mixtures. They are likely to suggest only some of the major significant variations in composition.

In the Recent sediments under consideration, preliminary X-ray diffraction data indicate the presence of a mineral (designated as montmorillonite) which expands to about 17 Å following treatment with ethylene glycol, a 14 Å nonexpanding mineral designated as chlorite, and a 10 Å nonexpanding mineral designated as illite. The diffraction data show reflections at about 7 Å and 3.5 Å which may be due to kaolinite and/or chlorite. A small amount of quartz and some random mixed-layer clay mineral components are present also.

Oriented aggregates of the minus-two-micron fraction are collected on glass microscope slides and diffraction data, using a recording spectrometer, are recorded for such aggregates without further treatment, following saturation with glycol, and after heating to 450°C. Diffraction data are also registered on films, using powders and oriented aggregates cut from the slides. Occasionally reflections which could not be established

[1] Published with the permission of the Chief.

with certainty without scaling on the spectrometer are unequivocal on the films.

The samples heated to 450° C. are brought to this temperature in about 45 minutes and then air-quenched. This heating procedure is an arbitrary one and was selected after much experimentation. The basis for the selection is that no kaolinite has yet been found by the authors which loses its diffraction effects by such heating. Therefore, diffraction effects at 7 Å and 3.5 Å which are lost by such heating cannot be due to kaolinite. Depending on its composition and crystallinity, chlorite may or may not lose its 7 Å and 3.5 Å reflections when heated to 450° C. and immediately quenched. As a general rule it may be concluded that the loss of 7 Å and 3.5 Å reflections under these conditions must be accounted for by chlorite. If such reflections are retained, they may indicate either chlorite or kaolinite. In the samples under consideration, the 7 Å and 3.5 Å lines were generally eliminated or diminished in intensity, indicating chlorite rather than kaolinite. In materials having chlorite of better crystallinity and greater thermal stability some other procedure must be evolved for differentiating the kaolinite and chlorite.

QUALITATIVE FEATURES

Even in complex mixtures of clay minerals one can determine readily the general attributes of individual constituents. More careful scrutiny, however, may reveal rather subtle variations of considerable import. In the case of the Recent sediments under consideration there appear to be two types of expanding components, the presence of a particular one being correlative with chemical environment. One has a normal basal spacing of about 15.5 Å when air-dried; the other a spacing of about 14 Å under similar conditions. The latter component is unique in that it exhibits properties common to both montmorillonite and chlorite. In its natural state, scattering distribution along the 00*l* row line is incompatible with that of definite chloritic material even though it shows the rational sequence of orders related to a 14 Å periodicity. On the other hand significant scattering contribution at an angle corresponding to 7 Å indicates an interlayer population in excess of that afforded by exchange cations alone in montmorillonite. One is prompted to speculate that in such cases the interlayer region consists of occasional "islands" of brucite scattered laterally at random over otherwise hydrated montmorillonite surfaces; this component takes on the general characteristics of a vermiculite, except for its ability to imbibe glycol and expand.

The chlorite component of these sediments also exhibits noteworthy features which depart from the norm. Especially characteristic are the abnormally low intensities of the odd orders of basal reflection as compared to the even orders. This feature is apparently a common characteristic of sedimentary chlorites, and its structural significance merits brief discussion. The quality of diffraction data from so poor a grade of crystal when it is encountered only as one component in a complex mechanical mixture does not permit a rigorous analysis of its nature. It becomes necessary instead to seek possible interpretations in terms of analogous situations met in instances of better crystallized minerals.

Among relatively well crystallized chlorites, instances are encountered in which the intensities of all odd orders of the basal reflections are too weak relative to the even orders to afford any solution for placement of their chemically analyzed empirical formulae in the sets of octahedral and tetrahedral interstices which comprise the conventional chlorite crystal structure. For such instances a simple one-dimensional Fourier synthesis of the differences between the importance of odd order reflections anticipated from the conventional model and of those actually observed indicates that some tetrahedral ions are actually located between the mica skeleton and the brucite

layer, rather than entirely within the mica skeleton. One successful complete analysis has been conducted by Brindley and Gillery (1953) for an instance in which this type of departure is regular on a unit basis, and two schematic analyses of related structures, sepiolite (Bradley, 1954), and attapulgite (Bradley, 1940), indicate regularity in a superlattice sense. The assumptions that irregularly disposed silicon displacements of this nature exist in the sedimentary chlorites, and that brucite development falls short of ideal, would together account for the observed anomalous intensity features. "Quantitative" estimation then depends upon utilization of the sequential basal intensities to establish the chloritic nature, after which the most normal looking individual order may be judged for intensity.

The chlorites in the sediments are characterized by their lesser development of interlayer brucite, as compared with their better crystalline counterparts such as may be encountered in metamorphic rocks. This is shown by the ability of the brucite layers to dehydrate at temperatures considerably lower than the latter chlorites. That these sedimentary chlorites invariably have montmorillonitic (or at least expandable layers) intermixed is revealed following thermal treatment. Thus, heating to only 200° C causes some reduction in intensity and migration of the 14 Å reflection.

It is also interesting to note that reflections indicative of a and b parameters indicate that the chlorite (and in fact all) components of these sediments are within the range characteristic of dioctahedral compositions.

Since in many cases resolution of diagnostic reflections occurring close together is poor, careful scrutiny of differences in peak profiles is imperative. Radiation which is being distributed in diffuse bands in the small angle range is subject to rapidly declining Lorentz, polarization, and powder halo corrections within the angular width of a single band. Accordingly before one can interpret the structural significance of peak asymmetry, one must reduce recorded intensities to terms of relative F or F^2 values. The influence is readily illustrated symbolically by adjusting one flank of a peak record to the other by a point by point application of the ratio of the respective reduction factors, according to the expression $I_{s_{corr.}} = I_s \frac{\phi(\theta_r)}{\phi(\theta_s)}$. $I_{s_{corr.}}$ and I_s are the corrected and observed intensities at a value of $\frac{\sin\theta}{\lambda}$ on the slope being adjusted; $\phi(\theta_s)$ and $\phi(\theta_r)$ are respectively the reduction factors of the point being adjusted and its reference point. The real shape of the low-angle diffuse feature is then apparent by inspection.

In mixtures of the type being considered, in the natural state a 14 Å reflection for chlorite is often masked by a diffuse reflection for montmorillonite occurring within this range. Following ignition to 450° C., a maximum at about 13.8 Å for chlorite is revealed, as the expandable component collapses to about 10 Å (solid line, fig. 1A). Using the high-angle slope of the 10 Å maximum as a reference and applying the proper intensity corrections to the low-angle diffraction effects this 14 Å maximum is reduced, but is still obvious (dashed line, fig. 1A).

In a great many cases in such clay materials, the presence of a 14 Å reflection following ignition is revealed only by a pronounced asymmetry of the 10 Å reflection toward low angles (solid line, fig. 1B). This asymmetry is retained, though reduced, even after angular intensity corrections are allowed for (dashed line, fig. 1B), demonstrating it to be a valid diffraction feature. In this case the asymmetry of the 10 Å reflection can be interpreted as the result of lack of resolution between the 10 Å maximum of illite and collapsed montmorillonite and a 14 Å maximum for chlorite, the higher orders of which are dimin-

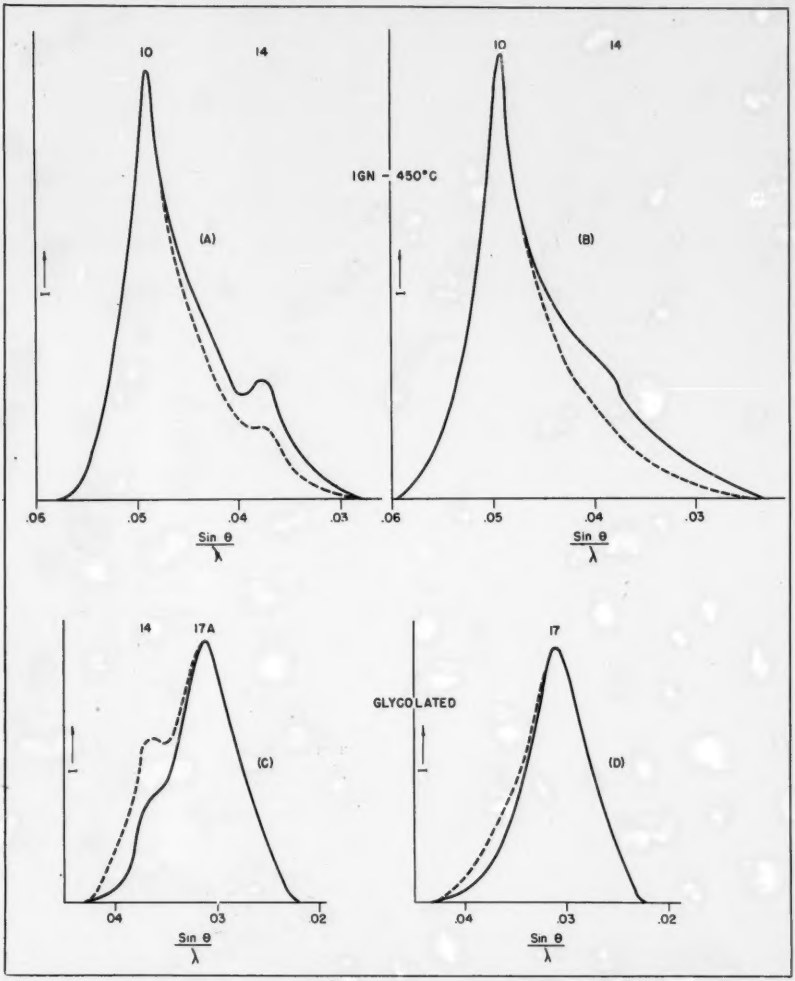

FIG. 1.—Typical examples of details of intensity distribution about diagnostic diffraction maxima following (a) and (b) ignition to 450° C., and (c) and (d) following glycol treatment. Solid lines are re-plots of intensity data taken from actual X-ray spectrometer traces; dashed lines represent data reduced to proportionality to F^2 utilizing opposite slopes as references.

ished or lost simultaneously with the appearance of the described low-angle features. This interpretation is further substantiated by treating in a similar fashion the maxima occurring in this region following glycol treatment. In this case also the 14 Å reflection for chlorite is never completely resolved from the

diffuse 17 Å peak for glycolated montmorillonite. In some cases the 17 Å reflection is modified by the appearance of a shoulder on the high-angle side (solid line, fig. 1C); often the 14 Å reflection is revealed only by the asymmetry of the low angle spacing toward higher angles (solid line, fig. 1D). Applying the appropriate angular intensity corrections in this case enhances these features (dashed lines figs. 1C and 1D). In this manner it is possible to evaluate the significance of unequal angular distribution of peak intensity. In theory, this analysis could be further pursued after the method of MacEwan (1953) to yield the degree of association of like layers as chlorite. Simple inspection indicates that the degree is high, and no further account is taken of it here. It is apparent that where identifications are doubtful, data derived from materials treated in a variety of ways are necessary to substantiate interpretations.

"QUANTITATIVE" FEATURES

The inherent weak character of some important basal reflections from the clay minerals limits even qualitative analysis of complex mixtures by ordinary powder techniques. Enhanced sensitivity is achieved by the use of flake aggregates. For each basal diffraction maximum, the energy, evenly distributed about a sphere in reciprocal space in the powder diffraction method, is concentrated within a small spherical segment of graded density about a single pole. Perfection of orientation varies from sample to sample, so that for any one sample the actual fraction of total diffracted radiation being counted by the spectrometer is indeterminate, but the perfection tends to be equal, for various components of a mixture, and relative counts may be utilized. It is observed empirically that distribution about each pole is of such latitude that decline of intensities received by a slit system with increasing angle follows powder laws more nearly than those for extended faces. Best accuracy obtains for comparisons at comparable diffraction angles.

Arbitrary features of this treatment are of such magnitude that absorption may be neglected, particularly for the ranges of iron content commonly encountered, and diffraction effects from any component may be treated as subject only to laws of simple dilution. The problem then is only to select a proper ordinate for some position on a working curve for each component. In an extended suite of specimens an automatic safeguard is imposed by the combinations of circumstances that the sum of all components is fixed, and that some individual instances are bound to be encountered in which the content of one specific component is quite high.

In figures 2 and 3 are shown smoothed spectrometer traces obtained from several samples of Recent sediment in the natural state as well as following glycol treatment and after heating to temperatures indicated. Consideration must be given to all three sources of data for proper evaluation of intensities. Below each curve uncorrected relative intensity values are given for those diffraction maxima utilized in making estimates of each clay mineral phase present. Although no intensity scale is indicated it should be noted that intensities are recorded logarithmically. The relative intensity data are again tabulated in tables 1 and 2.

In establishing the relative abundances of each constituent all components were compared to the illite phase within each sample. The glycol-treated sample was utilized in comparing the illite and montmorillonite components, considering intensity differences in the 10 Å and 17 Å reflections. The actual intensity measurements require consideration also. Related to the extremely poor crystallinity of these clay mineral constituents, within a given crystallite, parallel alumino-silicate layers deviate appreciably with re-

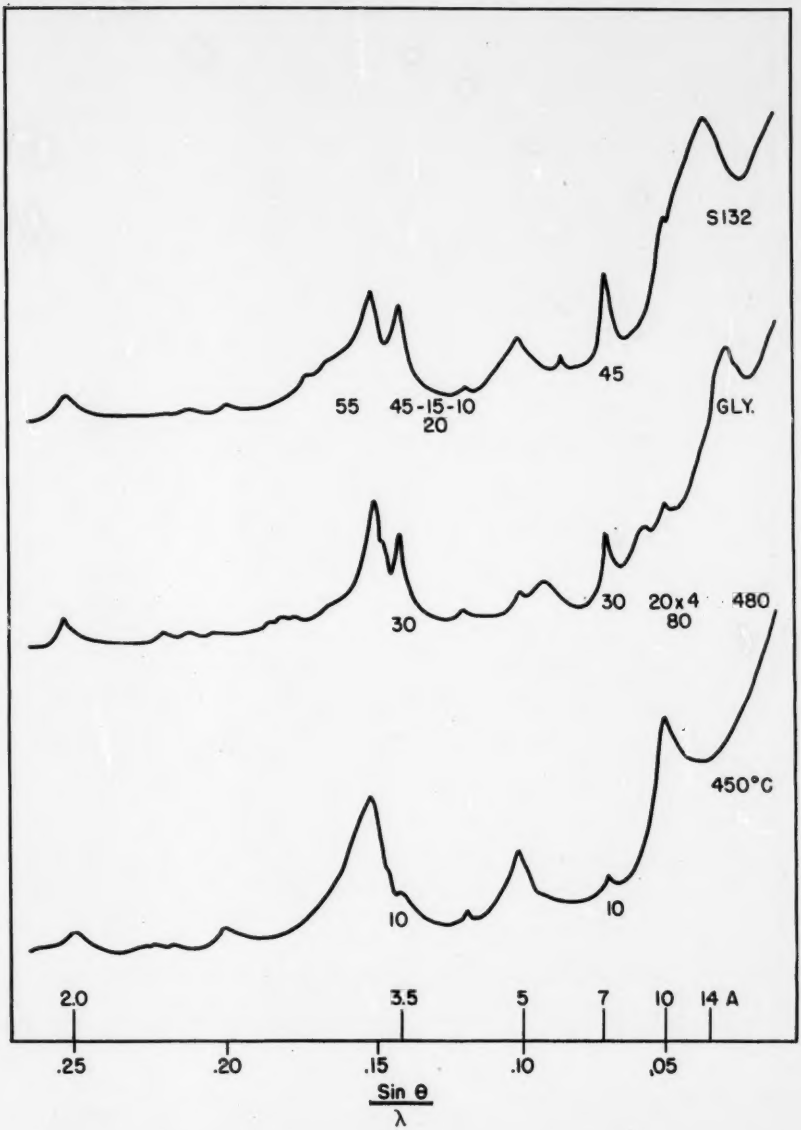

FIG. 2.—Smoothed X-ray spectrometer traces of sample S132 in the air-dried state, following treatment with ethylene glycol, and air-quenched following ignition to 450° C. Data obtained from oriented aggregates; numbers indicate intensities in counts per second.

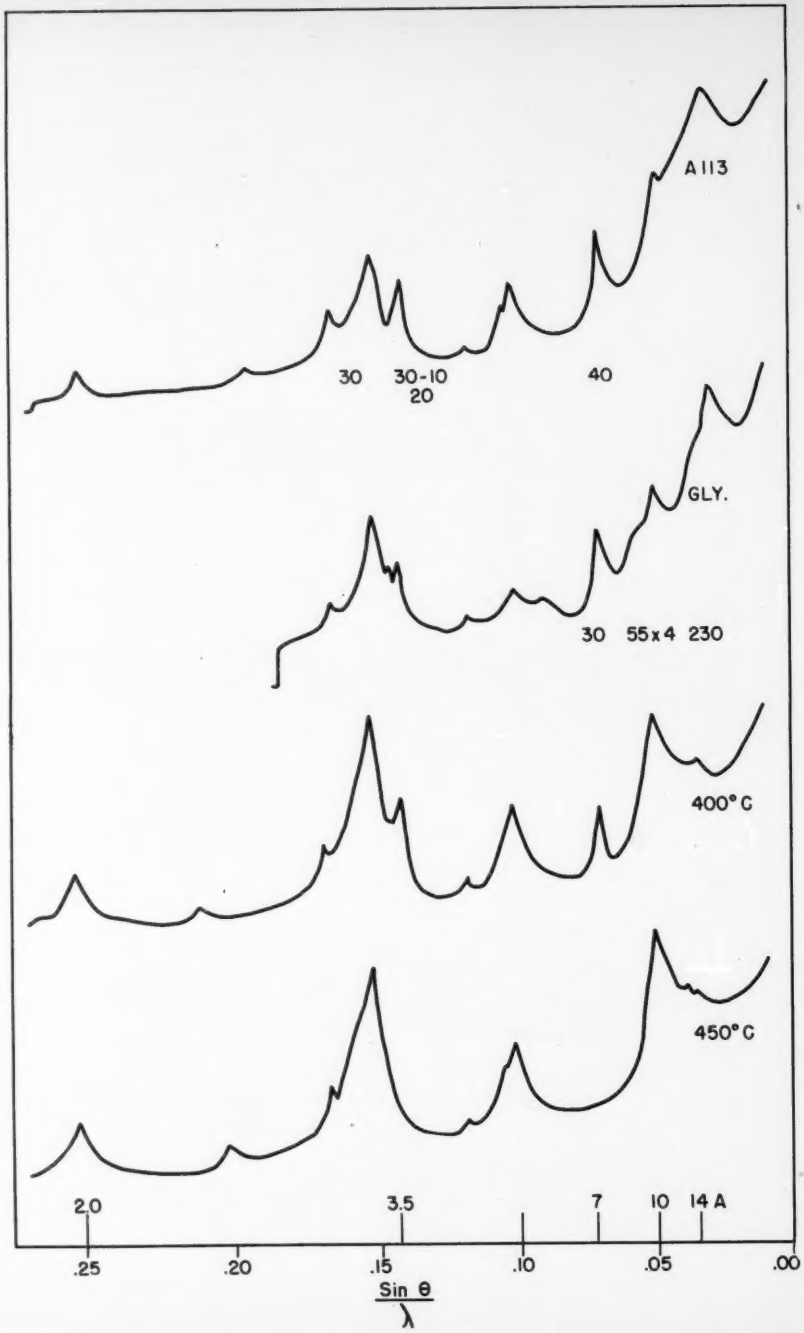
A113
30
30-10
20
40
GLY.
30 55x4 230
400° C
450° C
2.0
3.5
7
10
14 A
.25
.20
.15
.10
.05
.00
Sin θ
λ

TABLE 1.—*Analytical Data for Sample 132*

17 Å	10 Å	7 Å	3.5 Å	3.3 Å	Comments
		A. Relative Intensity Data*			
480	20				
	80				Illite corrected
				55	Illite corrected for quartz
		45	45		
		30	30		Corrected for montmorillonite
		10	10		Kaolinite corrected for chlorite
		20	20		Chlorite

Montmorillonite	Chlorite	Illite	Kaolinite	
	B. Clay Mineral Composition			
6.0	0.4	1.0	0.2	Parts per one part of illite
79	5	13	3	Approximate percentage of each constituent
7	0.5	1.0+	0.5−	Parts in ten of each constituent allowing 10 per cent for material not registering

* Intensity values based on direct counts.

TABLE 2.—*Analytical Data for Sample A113*

17 Å	10 Å	7 Å	3.5 Å	3.3 Å	Comments
		A. Relative Intensity Data*			
230	55				
	220				Illite corrected
				30	Illite corrected for quartz
		40	30		
		30	20		Corrected for montmorillonite
		0	0		Kaolinite, corrected for chlorite
		30	20		Chlorite

Montmorillonite	Chlorite	Illite	Kaolinite	
	B. Clay Mineral Composition			
1	0.7	1		Parts per one part of illite
37	26	37		Approximate percentage of each constituent
3.5	2.5	3.5		Parts in ten of each constituent allowing ten per cent for material not registering

* Intensity values based on direct counts.

spect to perfect periodicity as a result of frequent variations in interlayer distances. A maximum reading would merely indicate the mean or dominant periodicity characteristic of a given crystallite. Accordingly reflections related to the basal planes, instead of occurring at one precisely fixed angle of diffraction, occur over a small but appreciable angular range, particularly in the low-angle

FIG. 3.—Smoothed X-ray spectrometer traces of sample A113 in the air-dried state, following treatment with ethylene glycol, and air-quenched following ignition to 400° C. and 450°C. Data obtained from oriented slides; numbers indicate intensities in counts per second.

region; that is to say, instead of reflections being sharp and well defined they are broader and more diffuse than might be desired. An arbitrary integration procedure is therefore adopted which consists of summing the observed intensities over a sequence of angles surrounding each maximum. The relative intensities resulting from the summations of each series of readings then serve as a more accurate basis of comparison than single maximum values alone.

Considerations must be given to an additional factor before intensity data as obtained above for illite and montmorillonite can be compared directly. The efficiency with which a sheet-type silicate scatters along the 00*l* row line varies with sin θ/λ according to a form factor function. Data obtained by Bradley (1953) show that scattering from three-layer clay minerals at an angle corresponding to 17 Å exceeds by a factor of approximately four the reflected intensity of similar material contributing scattering at 10 Å. Thus the intensity values for illite as derived above must be multiplied by a factor of four before direct comparison can be made with intensity values at 17 Å for montmorillonite. Intensity data thus derived are given in the first two columns of tables 1 and 2 for samples S132 and A113 respectively.

Lack of precise information with regard to differences in form factor functions for illite, chlorite, and kaolinite render quantitative comparisons of these constituents more difficult. However, within the range corresponding to sin $\theta/\lambda = .15-.16$, or where $d_{00l} = 3.3-3.5$ Å, it is believed that scattering distribution is sufficiently constant that the 3.5 Å maximum for chlorite and kaolinite can be compared directly with the 3.3 Å reflection for illite as a means of relative estimation within a given sample. Diffraction data from the untreated samples are most useful in this respect. The 3.5 Å reflection corresponding to the 4th order for chlorite and the 2nd order for kaolinite are compared to the 3rd order reflection (3.3 Å) of illite. Relative intensity data for the 3.3 Å reflection of illite, corrected for a small amount of quartz contaminant, is given in column 5 of tables 1A and 2A for samples S132 and A113 respectively.

Three possible components contribute to the 3.5 Å maxima, namely, chlorite, montmorillonite, and kaolinite. Reduction in intensity of this reflection following glycol treatment can be accounted for by montmorillonite. Following ignition to 450° C. any diffraction effect noted at 3.5 Å can be attributed to kaolinite. Inasmuch as the 3.5 Å and 7.15 Å peaks are of comparable intensity these changes can be most readily observed by noting the effects of firing and glycolation on the 7.15 Å reflection. Intensity data for these reflections are given in columns 3 and 4 of tables 1 and 2 for samples S132 and A113 respectively. Thus in the case of sample S132 the intensity at 3.5 Å in the natural state is 45 and drops to 30 following glycol treatment; following ignition to 450° C. the value drops to 10. Accordingly the intensity contribution of chlorite is 20; kaolinite is 10. These latter values can therefore be compared to the intensity value at 3.3 Å for illite (55) to estimate relative abundances.

The corrected relative intensity data given in tables 1A and 2A can now be utilized in estimating the relative abundance of each constituent present using illite as a sort of internal standard or common denominator. For sample S132 for example, the ratio of 10 Å and 17 Å intensities for the glycol treated sample indicates 6.0 parts montmorillonite for each part of illite; likewise comparison of the 3.5 Å intensities for chlorite and kaolinite with the 3.3 Å reflection for illite indicates 0.4 and 0.2 parts chlorite and kaolinite respectively for each part illite. Translating these data into parts per 10 of each constituent for the *total clay mineral constituents*, and allowing 10

per cent of the total for poorly crystalline phases not accounted for, the ultimate analysis for sample S132 results in 7 parts in 10 montmorillonite, 0.5 chlorite, 1.0+ illite, and .5− kaolinite.

Analysis of sample A113 in the same manner, table 2, results in 3.5+ parts in 10 montmorillonite, 2.5 chlorite, and 3.5 illite.

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JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 24, NO. 4, PP. 252–254
FIGS. 1–2, DECEMBER, 1954

MICROSTYLOLITES IN A RHYOLITE PORPHYRY

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ABSTRACT

The highly unusual occurrence of a diminutive stylolitic structure in a rhyolitic rock is described, and the evidence for the structure's secondary nature is discussed. Solution along these structures, with removal of both quartz and feldspar, is strongly indicated by the partial removal of spherulites and phenocrysts and by the concentration along these microstylolitic seams of the iron oxides which are otherwise more disseminated in the matrix of the rhyolite porphyry. Universal stage observations along these structures indicate their three dimensional irregularity and interpenetrating nature.

INTRODUCTION

During the study of a volcanic breccia from the Burin Peninsula, Newfoundland, the writer observed some microscopic structures (figs. 1 and 2) which definitely conformed to Pettijohn's (1949) definition of a stylolite, namely, "a stylolitic seam is a surface of contact marked by interlocking or mutual interpenetration of the two sides. The teeth-like projections of one side fit into sockets of like dimensions on the other."

The structures were believed worthy of description because, to the writer's knowledge, no stylolites of either macroscopic or microscopic size have as yet been reported from igneous rocks; all previously reported stylolites, other than those in the carbonate rocks, appear to be confined to sandstones, quartzites, and gypsum (Stockdale, 1936; Sloss and Feray, 1948; Conybeare, 1949). The stylolites to be described are unusual in that they occur in a rock of mixed composition whereas Pettijohn (1949) noted relatively recently that stylolites were not observed to appear in such rock types.

LITHOLOGIC OCCURRENCE

The microstylolites examined occur in fragments of a brecciated rhyolite porphyry the interstices of which are filled with pyroclastic materials, fluorite, or quartz. The structures appear to be limited to the fragments and were evidently formed in the porphyry prior to its brecciation.

The rhyolite porphyry consists of phenocrysts of quartz and feldspar embedded in a groundmass of microlitic quartz and orthoclase. In places this ground mass is spherulitic. Flow structures, marked by linear concentrations of the iron oxides ordinarily dispersed through the matrix, are also present. In all the examples noted, the microstylolitic structures were at an angle to the flow structure.

DESCRIPTION AND DISCUSSION

The interpenetrating nature of the microstylolites is seen in figures 1 and 2. In general, as higher magnifications were used the irregular nature of the structures became clearer. With the thin-section mounted on the universal stage it was noted that when some portions of the microstylolitic surface were brought to verticality, adjacent portions varied considerably therefrom. Points where the microstylolitic surface paralleled the plane of the thin-section coincided with apparent discontinuities of the microstylolite as observed in the non-tilted slide. From these observations the interpenetrating nature of the interfaces in question was established to be similar to that of typical stylolitic seams.

As may be seen from the photograph,

a concentration of opaque material exists along the microstylolitic seams. This material, under reflected light, appears identical to the iron oxides which are interspersed in the matrix of the rhyolite porphyry. Solution, therefore, has occurred along the interface to remove quartz and feldspar and thereby concentrate the less soluble iron oxides. To quote Pettijohn (1949) "the stylolitic seam is characterized further by the concentration of the insoluble constituents of the rock—such as clay, iron oxide, quartz sand, and silt particles. Accumulation of this residue along the surface—in greatest amounts at the ends of the columns—is best evidence of the solution origin of this feature."

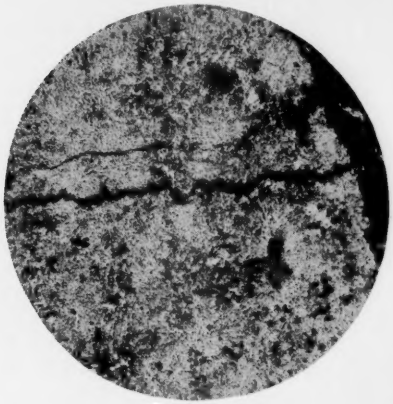

FIG. 1.—Photomicrograph of microstylolitic structure cutting the matrix of the rhyolite porphyry. (Transmitted light; ×35).

The microstylolitic structures intersect the spherulites and microlites in the matrix, the phenocrysts, and the previously cited flow structures as well. All were observed to display the independence of rock texture and structure commonly attributed to stylolitic surfaces. Spherulites and, under high magnification, the microlites of feldspar and quartz were noted to terminate abruptly upon intersection with this structure. The transection of a quartz phenocryst is shown in figure 2. This particular phenocryst showed no undulatory extinction or other evidence of optical strain under crossed nicols; a few small fractures were observed.

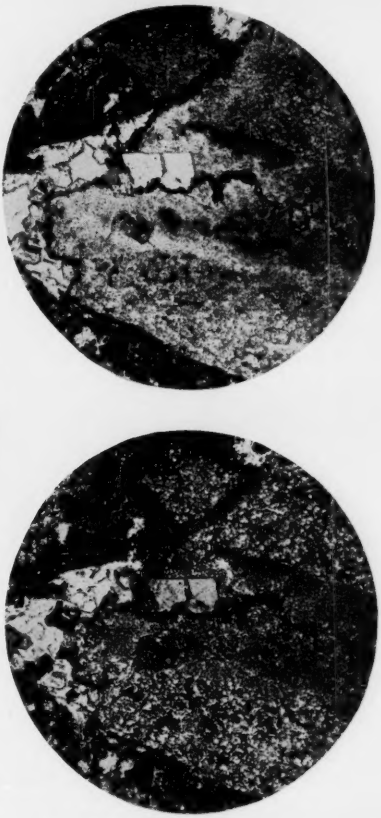

FIG. 2.—Photomicrographs of a breccia fragment of the rhyolite porphyry. The microstylolite cuts a quartz phenocryst but terminates at the fragment's contact with the quartz and fluorite filling (to left of phenocryst). (Upper, transmitted light; lower, crossed nicols; ×12).

From these observations it seems reasonable to conclude that these microstylolitic structures are secondary in nature, being younger than the spherulites, microlites, and phenocrysts. From the observation of the transected phenocryst itself it may be concluded that the rhyolite porphyry must have been well solidified during the development of the microstylolitic seam, the phenocryst having been undoubtedly held in a rigid matrix at this time.

CONCLUSIONS

1. The microstylolites described are well explained by the theory of secondary origin elucidated by Stockdale (1943).
2. Stylolites are not limited in occurrence to sediments or meta-sediments; conditions for their development may exist in igneous rocks although rarely.
3. Stylolites can develop in rocks of mixed composition.

ACKNOWLEDGMENTS

The writer wishes to thank the Reynolds Mining Corporation and in particular, Dr. Frederick C. Kruger, for permission to photograph and describe the microstylolitic structures. Professor F. J. Pettijohn of Johns Hopkins University and the writer's colleague, Professor Paris B. Stockdale, read and criticized the manuscript. All views expressed, however, are the responsibility of the writer.

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FIGS. 1–2, PLS. I–II, DECEMBER, 1954

DIAGENESIS OF PENNSYLVANIAN LIMESTONES, UPPER PECOS VALLEY, NEW MEXICO[1]

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ABSTRACT

Three varieties of limestone are distinguished: (1) microcrystalline or granular, more than 50 percent of the rock granular; (2) crystalline, composed mainly of sutured anhedra; (3) fragmental, consists chiefly of calcite fragments, quartz grains, and organic remains. Limestones especially susceptible to metasomatic replacement include the medium-bedded crystalline and fragmental varieties. Thin sections and photomicrographs show that diagenesis of various constituents follows a definite sequence: (1) for carbonates, aragonite or calcite to calcite to dolomite; (2) for silica, opal to chalcedony to quartz. Metasomatic materials are derived in part from associated sediments and in part from the host rocks.

INTRODUCTION

The Pennsylvanian sediments in north central New Mexico were deposited in the southern extension of the Colorado zeugogeosyncline. Maximum development of this trough was in Pennsylvanian time but it continued as an area of subsidence in the Lower Permian. The total thickness of the Pennsylvanian sediments is approximately 3500 feet. Rocks of questionable Pennsylvanian age are unconformable above granites and gneisses of the pre-Cambrian complex. The upper part of the section grades upward through a thick series of coarse clastics into somewhat similar Permian sediments.

The area studied is in the vicinity of the town of Pecos, located on the south and west dip slope of the Sangre de Cristo mountains (fig. 1).

Texturally, three varieties of limestone are distinguished: (1) microcrystalline or granular, more than 50 percent of the rock granular; (2) crystalline, composed chiefly of sutured anhedra; (3) fragmental, consisting chiefly of calcite fragments, quartz grains, and organic remains.

The granular limestones are light gray to greenish gray, dense, and medium-bedded; some units are flaggy. All of these limestone units, characterized by a limited organic content, are associated with ferrous clay minerals which impart the gray or green color (Keller, 1953). Most of the granular limestones are composed of light gray to greenish gray granular clusters which under crossed nicols produce a light and dark mosaic pattern. A few of the limestone units consist of individual carbonate granules each bordered by a thin layer of opaque material, apparently clay. Enclosures of clear anhedral calcite and isolated, subrounded grains of quartz are common.

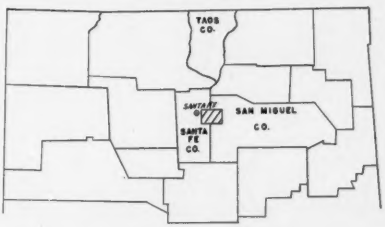


FIG. 1.—Map of northern New Mexico with the general location of the study area cross lined.

The crystalline limestones are light gray to dark gray, moderately dense, and medium to thin bedded; some units are nodular. They consist chiefly of anhedral

[1] Presented in part at the SEPM, AAPG meeting, Houston, Texas, April 1953.

TABLE 1.—*Stratigraphic section of the Pecos area*

System	Group	Formation	Member
Upper Triassic	Dockum	Santa Rosa	
Permian		San Andres	Siltstone or clastic Limestone Glorieta
		Yeso	
		Sangre de Cristo	
		—Transitional Beds—	
Pennsylvanian	Magdalena	Madera	Arkosic limestone Lower gray limestone
		Sandia	Clastic Lower limestone
Pre-Cambrian		Undifferentiated	

calcite or dolomite, irregular grains of silica, and a few dark gray granular clusters. The calcite and dolomite grains are usually sutured, some are clear, others are clouded by the inclusion of dark gray granules. Well developed oblique cleavage, often in two directions, is exhibited by some of the grains. Wavy or undulate structure, usually associated with crystal growth, commonly occurs along the cleavage planes and in contact zones between the replacement materials and the host rock.

The fragmental limestones, in respect to origin, composition, and association, are subdivided into three groups, normal, calcareous, and arkosic. Normal fragmental limestones, the largest group, are light gray to brownish gray, thin to medium bedded. Most units are less than 20 feet thick. They consist chiefly of partly rounded calcite fragments, subangular to subrounded quartz grains, and slightly worn organic remains, especially algae, crinoid columnals, brachiopods, bryozoans, sponges, and corals. The limestones are associated with arenaceous sediments and probably accumulated in the shallower parts of the epineritic environment.

A second type, composed primarily of calcareous fragments, occurs in the upper 30 feet of the limestone member of the Sandia formation. It is associated with normal marine limestones and consists of white to dark gray angular fragments ranging from a few millimeters to more than one inch in diameter. The high degree of angularity suggests that fragments were formed by the fracturing of limestone layers under subaqueous conditions.

A third type, arkosic fragmental limestones, occurs in the arkosic limestone member of the Madera. They are light gray to reddish gray and massive. They occur in relatively thin units, associated with red and green arkosic sandstones, clays, and shales. The chief constituents include medium to coarse angular grains of feldspar and quartz, greenish gray silts, and a few organic remains such as brachiopods, crinoids, sponges, and bryozoa. The accumulation of the sediments was influenced by regional uplift and probably represents a late stage in the geosynclinal environment. Deposition fluctuated markedly from rapid to slow and was frequently interrupted by intervals of erosion.

TECTONO-ENVIRONMENTAL CONDITIONS

Four tectono-environmental conditions

TABLE 2.—*Showing the percentage range of insoluble residues for the various types of limestones*

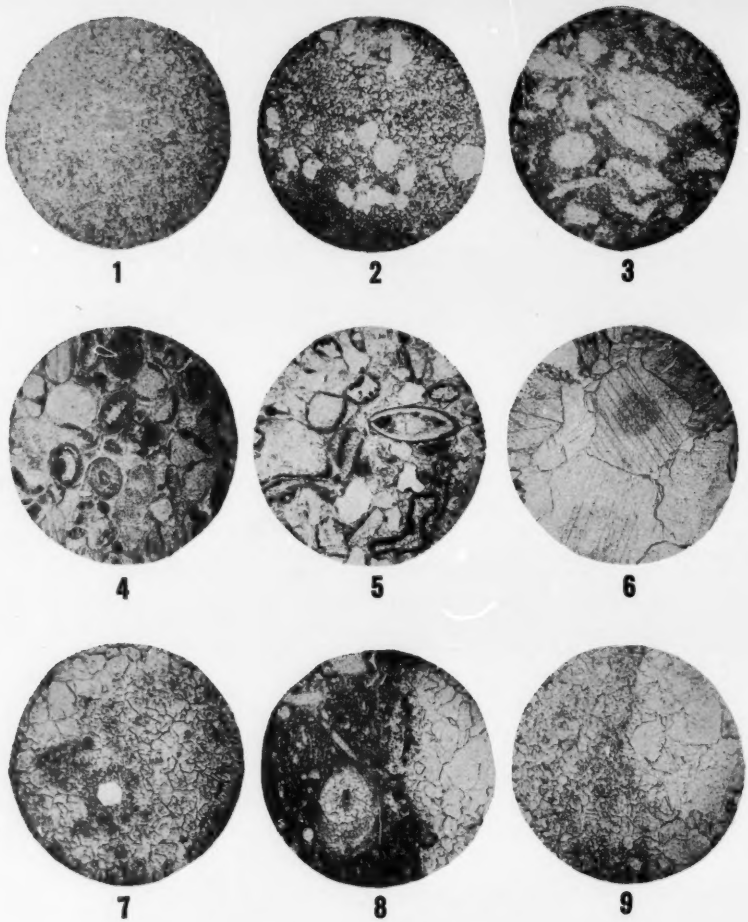
Member	Type of Limestone	Percentage Range	Average Per Cent
Arkosic limestone member of Madera	Crystalline	28.8– 2.7	16.2
	Granular	26.6–12.0	18.9
	Fragmental	27.8– 3.7	16.1
Gray limestone member of Madera	Crystalline	37.2– 3.6	17.1
	Granular	22.8– 0.9	17.8
	Fragmental	36.2– 4.6	15.1
Clastic member of Sandia	Crystalline	39.2–	39.2
	Granular	46.8–26.8	36.8
	Fragmental	47.8–16.2	31.5
Lower limestone member of Sandia	Crystalline	36.8– 3.8	14.4
	Granular	7.2– 0.5	3.7
	Fragmental	3.9–	3.9

are represented, (Krumbein, Sloss, and Dapples, 1949). Each environment corresponds to a distinct member. The lower limestone member of the Sandia represents a borderline epineritic-infraneritic environment on a moderately stable shelf. The upper clastic member of the Sandia represents a fluvio-lacustrine-eolian environment on an unstable shelf. The gray limestone member of the Madera represents both shallow and deep water phases of the infraneritic environment on a slightly unstable shelf. The arkosic member of the Madera represents the transitional environment on an unstable shelf (Sidwell and Warn, 1953).

The limestones in each of the tectono-environments are distinguished by characteristics such as thickness, shape(thickness compared to horizontal extent), organic content, lithologic association, and insoluble residues. In the lower limestone member of the Sandia (epineritic-infraneritic environment) the limestones, more than 60 percent crystalline, are light gray to dark gray and the units are dense, nonfossiliferous, and more than 20 feet thick. They have a wide horizontal range, predominate over clastics, and are associated with sheet sandstones. The insoluble residues in order of abundance are rounded to sub-rounded quartz grains, white, sugary opaline material, small amounts of gray and yellow clay minerals, and a few mica flakes.

The limestones in clastic member of the Sandia (fluvio-lacustrine-eolian environment) are subordinate to the clastics. They consist chiefly of lenticular units associated with varicolored, poor to medium sorted, lenticular sandstones and micaceous shales. Organic remains are abundant, consisting mainly of algae, crinoid columnals, bryozoa, and coral. The insoluble residues, chiefly sand sizes, consist of angular to subrounded quartz grains, quartzite fragments, mica flakes, aggregates of gray and yellow clay, iron oxide, and gypsum.

The limestones in the gray limestone member of the Madera, comprise about 30 percent of the total deposit. They represent both shallow and deeper water phases of the infraneritic environment. The limestones representing the shallow water phase contain characteristics which are comparable to those in the normal marine variety, (Dapples, Krumbein, and Sloss, 1948). They are light gray to dark gray, medium-bedded, of uniform texture, and are associated with micaceous shales. Those representing the deep water phase are dark gray, cherty, and are associated with partly indurated splintery shales. Organic remains common to both environments include crin-



LEGEND FOR PLATE 1

FIG. 1.—Dense, dark gray granular limestone with a few small grains of secondary opal and calcite. The insoluble residues, less than three percent, consist chiefly of clay minerals.

FIG. 2.—Microcrystalline limestone with irregular grains of secondary opal (light areas). The opaline grains contain small, darker inclusions of calcite.

FIG. 3.—Dark gray to black granular limestone with clusters of metasomatic calcite. Probably the host rock consisted largely of dark clay, and organic and calcareous mud.

FIG. 4.—Dark gray fragmental limestone with organic remains, chiefly algae and possible oolites. The light colored infill in the algae consists of calcite. The shaded materials are granular calcite or aragonite.

FIG. 5.—Fragmental limestone. The chief constituents are: both allogenic (a) and secondary (c) quartz grains; granular and secondary calcite; and a few organic remains.

oidal fragments, brachiopods, gastropods, bryozoa, and foraminifera. The insoluble residues in order of abundance are gray nodular chert, aggregates of gray to greenish clay, and medium textured sands, quartz, mica flakes, and hematite.

In the arkosic limestone member of the Madera, the limestones represent the transitional environment and consist of gray, medium-bedded, massive units associated with red and green arkosic shales and sandstones. Organic remains are fragmental, consisting chiefly of crinoids, brachiopods, gastropods, and bryozoa. Insoluble residues, as much as 28 percent of the rock, consist of angular quartz grains, mica flakes, chert fragments, feldspars, gypsum, iron oxide, and aggregates of red, yellow, and gray clays.

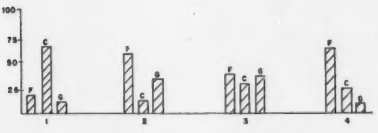


FIG. 2.—Abundance of limestone types in each of the tectono-environmental conditions. Fragmental limestones (F); crystalline limestones (C); granular limestones (G). The borderline epineritic-infraneritic environment, (1); the fluvial-lacustrine-eolian environment, (2); the infraneritic environment, (3); the transitional environment, (4).

DIAGENESIS

Diagenesis in Pennsylvanian limestones of this study is highly localized. Some units are practically by-passed; others are congenial hosts. Limestones especially susceptible to metasomatic replacement include the thin- to medium-bedded crystalline and fragmental varieties. Thin sections and photomicrographs show that various constituents in limestones follow a definite sequence: (1) for carbonates, aragonite or calcite to calcite or dolomite; (2) for silica, opal to chalcedony to quartz.

Metasomatic limestones are distinguished from the original carbonates by characteristics such as: (1) enclosed islands of original material, usually calcite; (2) concave surfaces in the host rock at the crystal contacts; (3) sawtooth protuberances in the contact zone; (4) dolomite or siliceous oolites; (5) grains of calcite or quartz showing two or more successive stages of growth; (6) replacements with preservation of original structures.

Metasomatic calcite is represented by replacement materials and by fissure fillings. The latter, indirectly related to metasomatism, consists of veins of crystalline calcite which commonly dissects the planes of separation in the limestones. The degree and type of alteration suggests an age discrepancy in the vein filling materials. In most recent fillings, the calcite is practically unaltered and the contact with the adjoining rock is sharp. In less recent fillings, the calcite grains show evidence of solution and recrystallization, and the contact zone between the vein material and adjoining rock is irregular and indefinite. Various stages of solution and recrystallization are evident in thin section studies. Most of the calcite in the vein filling was probably derived from sediments adjoining the limestone units.

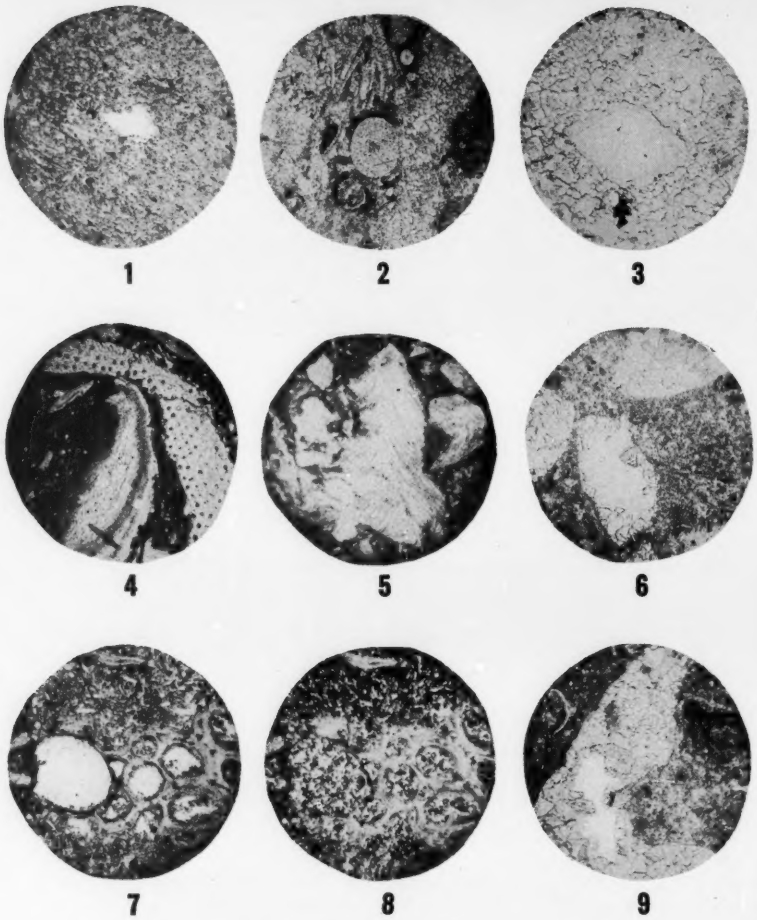
Metasomatic calcite supersedes arag-

FIG. 6.—Crystalline limestone with few grains of metasomatic quartz. Oblique cleavage is well developed in the calcite. The shaded masses in the center of the calcite grains is partially replaced granular calcite.

FIG. 7.—Crystalline limestone with isolated grain of euhedral quartz. The shaded area surrounding the quartz consists of finely granular calcite.

FIG. 8.—Dark gray massive limestone with clusters of metasomatic calcite enclosed by granules. The large calcite cluster shows the growth sequence from interior outward (large nuclear crystal followed by smaller grains).

FIG. 9.—Crystalline limestone with granular matrix. The large grains are probably metasomatic since they incorporate the smaller, apparently original granules.



LEGEND FOR PLATE 2

FIG. 1.—Shaly limestone with secondary opal (irregular light areas) and siliceous spines.

FIG. 2.—Fragmental limestone composed chiefly of crystalline metasomatic calcite, granules and a few organic remains. The original material and structure has been removed from the large circular grain. Under crossed nicols the small circular grain shows the original radial structure

FIG. 3.—Crystalline limestone with a large dolomite rhomb. The rhomb consists of a well developed central core with oblique cleavage and a narrow marginal transitional zone representing a secondary growth stage.

FIG. 4.—Fragmental limestone showing two large clusters of chalcedony. The chalcedony is a replacement after organic remains.

FIG. 5.—Under crossed nicols. The large central specimen is a chalcedonic aggregate composed of parallel fibers with chevron-like pattern. Incomplete stages of development show in surrounding fragments.

onite as well as some of the original fine-grained calcite. The development of the metasomatic aggregates appears to follow a definite sequence: (1) the development of a focal area consisting of one or more medium to large subhedra; (2) the formation of a surrounding zone of two or more rows of smaller anhedra; (3) the eventual coalescense of the aggregates to form large irregular masses (pl. 1, figs. 3, 7, 9).

Many of the granular limestones result from repeated secondary growth of calcium carbonate on microscopic grains or nuclei (pl. 2, fig. 6). Such limestones may become crystalline and eventually alter to dolomite. Fragmental limestone frequently shows secondary growths and replacements resulting in a partly crystalline texture.

Dolomite occurs as irregular grains, as clusters, and occasionally as isolated rhombs (pl. 2, fig. 3). It supersedes metasomatic calcite as well as some of the original calcite. The growth pattern for the clusters is from the interior outward and is similar to the growth sequence for calcite. It consists of one or more medium to large nuclear grains, a surrounding zone of smaller anhedra enclosed by granular or anhedral calcite. The rhombs consist of a well developed central core and a marginal gradational zone, an indication that the growth is from the interior outward. The central core, about 80 percent of the crystal, usually shows two directions of well developed oblique cleavage terminating in the marginal zone. The gradational marginal area consists of light to dark gray granules of calcite and dolomite.

The metasomatic cycle for silica commonly represents a mineral change from opal to chalcedony to quartz. The original silica probably occurred in colloidal state and coagulated as opal, the cryptocrystalline variety. It shows in thin sections as a replacement material after calcite and dolomite, as a cementing material, and as overgrowths (pl. 1, fig. 2; pl. 2, fig. 9).

Chalcedony is concentrated in the organic fragmental limestones which represent the infraneritic environment. The growth sequence, opal to chalcedony, from the interior outward includes: a nucleus area of fibrous silica usually near the center of the opaline mass, a thin dark colloform layer, and a zone of white to gray non-crystalline silica. Chalcedony under crossed nicols shows three distinct patterns, mosaic, parallel, fibrous, and a combination mosaic-parallel fibrous. The mosaic pattern consists of light and dark fibrous aggregates enclosing scattered granules of opal. Most of the grains with a parallel fibrous pattern are concavo-convex and consist of two rows of inclined parallel fibers converging at the center of a grain forming a chevron-like pattern. The combination pattern consists of a mosaic infill enclosed by concentric parallel fibers. All of these patterns are striking in texture and color under crossed nicols (pl. 2, figs. 4, 5, 7, 8).

Two types of quartz, allogenic and metasomatic, are represented in the limestones. The characteristics of the metasomatic quartz as revealed by thin sections are: (1) inclusions of carbonate or opal; (2) quartz grains in oolites and in organic remains, especially the walls of shells; (3) a zone of calcite or opaline

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FIG. 6.—Granular limestone. The metasomatic clusters are partly replaced with opal (irregular light patches). Many of the calcite granules contain original growth nuclei.

FIG. 7.—Fragmental limestone. The chief constituents are calcite granules, organic remains, especially bryozoa and spines, and chalcedony. The chalcedony infill contains inclusions of the original limestone.

FIG. 8.—Same as specimen 7, under crossed nicols. The chalcedony shows a mosaic pattern.

FIG. 9.—Fissure filling in granular limestone. Age relationships, oldest to most recent, include: original dark colored granular calcite, infill of crystalline calcite, irregular grains of metasomatic opal.

inclusions between the original quartz and the outer zone; (4) well developed isolated euhedra; (5) optical discontinuity within grains.

Metasomatic quartz is represented by isolated grains, by aggregates consisting of two or more grains, and by overgrowths (pl. 1, figs. 5, 7). The isolated grains, anhedra to well developed euhedra, range from microscopic dimensions to one millimeter in diameter. The aggregates, variable in size and shape, project irregularly into the host rock. They consist of closely packed anhedra which, under polarized light, appear as one large grain.

SOURCE OF METASOMATIC MATERIALS

The metasomatic materials in limestones are probably derived from two general sources: (1) solution and transportation by percolating water from sediments outside the limestones; (2) solution and reprecipitation of original constituents within the limestone units. Megascopic and thin section studies reveal strong evidence supporting the latter as the important and chief source for the replacement materials. Some of the observations include: (1) the limestones are fairly impervious to circulating water excepting joints and bedding planes, and the metasomatic process has little relation to such structures; (2) the metasomatic process is concentrated in fragmental limestones, consisting chiefly of organic remains, a few carbonate fragments, and granular calcite. These constituents are less stable than the replacement materials and serve as hosts for the metasomatic process; (3) the low porosity in the limestones and the occurrence of replacement materials in clusters suggest that the metasomatic process is probably preceded or simultaneous with solution and recrystallization of the original constituents; (4) organic remains such as spicules of sponges (pl. 2, fig. 1) and silicate minerals, especially feldspar and biotite, are probably the chief source for the silica. The former are abundant in the organic fragmental limestones; the latter in the arkosic limestones. Considerable amounts of opal, in finely divided and diffused form, are the obvious source materials for calacedony replacement in many of the fine-grained limestones.

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A SIMPLE CORING TUBE FOR SOFT SEDIMENTS[1]

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ABSTRACT

A simple hand operated core barrel with following features:
1. Operated by one or two men depending on length of core cut and depth of water.
2. Relatively light weight.
3. Double tube barrel, inner plastic tube and core easily removed.
4. Ball check valve in top of inner tube eliminates need for core catcher.
5. Has been used in water 15 feet deep.
6. Cutting core causes almost no turbidity in water on top of core resulting in excellent cores for skin studies.
7. Cuts 2¾ inch O.D. cores but design can be used for other diameters.

INTRODUCTION

For a number of years the writer has been studying recent sediments in three dimensions, together with rates of deposition. During the later years of this study a rather simple coring tube has been developed which has given quite satisfactory results in the softer sediments.[2] Clays with densities as low as 1.3, as well as soft sands, have been successfully cored with very little distortion. In addition, virtually no turbidity is caused in the cutting of the core and, in consequence, the upper skin of the bottom is recovered virtually undisturbed. This is due partly to the lack of any bottom end core catching device. The lack of bedding distortion as well as the undisturbed character of the surface skin are probably the two most useful features of the device. Cores up to six and seven feet in length have been taken in clays and laminated sands with little trouble. Many shorter cores of both clay and sand have been taken. Cores longer than seven feet should be secured with little trouble. Eleven and one half foot sections have been cored by taking several short cores. To secure these sections, casing was set at a depth slightly less than the short core length, cleaning out the casing, then coring below bottom of casing so cores overlap. Galvanized iron tubes were used for casing.

Several persons who have seen the tube in operation have been given specifications and were well pleased with the coring results. Thinking others might be interested also, the writer is giving specifications and the general method of operation. Probably some changes in specifications and improvement of technique will give even better cores.

In deciding on a desirable diameter for cores several factors were considered early in the writer's study of recent sediments. The I.D. of the core barrel should be sufficiently large to prevent as much by-pass as possible, but not too large to prevent handling with relative ease. The core needed to be of sufficient diameter to give adequate material for study. For skin studies, such as life and death counts of foraminifera and isopachus determinations, a fair sized diameter seemed desirable. Rightly or wrongly, a core diameter of 2¾ inches was decided upon. Larger cores, it seemed would be difficult to handle, and smaller

[1] Published with permission of the Gulf Oil Corporation.

[2] Charles A. Aves, Frank Gregg and Paul Sloan participated in the design development. Their help and cooperation was appreciated. Drafting of the assembly drawing was done by Zinn R. Northrup. Herbert M. Oliver, Jr. helped in the preparation of the manuscript. All are employees of the Gulf Oil Corporation.

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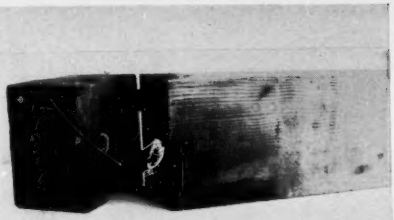

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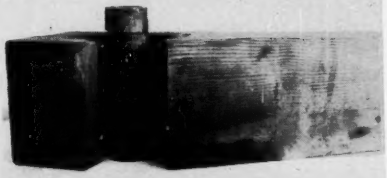

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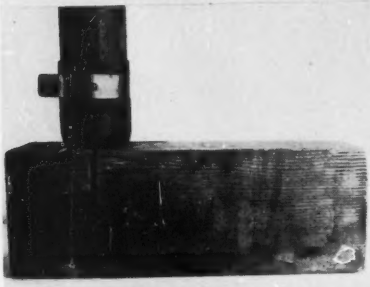

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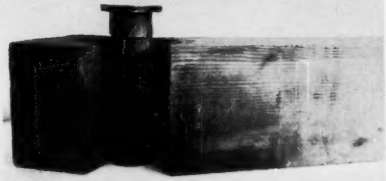

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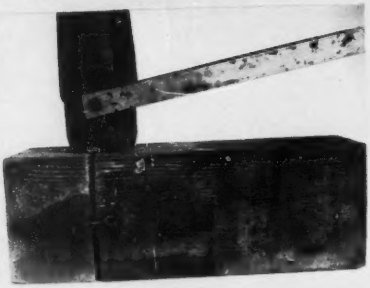

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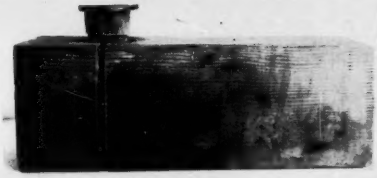

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would not furnish sufficient material, as well as tending toward greater amount of by-pass. However, the specification dimensions can be reduced or enlarged to any desired diameter. Probably tubes of several diameters should be used in any extended program of recent sediment coring.

The writer's coring activities have been done on foot, from skiffs, 30-foot twin screw speed boats, and 25- to 50-foot shrimp luggers. Since hand operation seemed to be most expedient in water up to about 15 feet in depth, a core barrel sufficiently light for hand operation by two men was a necessity. A single tube core barrel was ruled out as undesirable for the work being done, even if a double tube barrel would add slightly to the weight. Three inch O.D. brass tubing (11)[3] with a wall thickness of 0.042 inches was available in 12 foot lengths with a weight of 1.44 pounds per foot or 17.28 pounds for the 12 foot length and with a wall thickness of 0.049 inch in 12 foot length with a weight of 1.67 pounds per foot or 20.04 pounds for the 12 foot length. Clear plastic tubing (12) of $2\frac{3}{4}$ inches I.D. with a wall thickness of .05–.06 inch was found to be available in 12 foot lengths. These weigh 2.98 pounds for the 12 foot lengths. Double tube barrels, of course, require some type of cutting head (19), but for best results it needs to be as thin walled as possible. The head in present use has a wall thickness of $\frac{1}{4}$ inch and is thick enough for satisfactory clamping by two spring clamps (14) of phosphorus bronze. The first core head made was of yellow brass and weighs 1.54 pounds. Additional core heads have been of stainless steel. The check valve (5–10) placed in the top of the plastic tube weighs 1.1 pounds.

Several methods have been used for keeping the plastic tube in place during core cutting operation, but the insertion of a $2\frac{1}{2}$ inch O.D. aluminum tube (2) in the top has been found to be quite satisfactory. In cutting underwater cores, it has been found that a foot or so of water should be allowed between the top of the core and the check valve. Different lengths of plastic tubes are used, depending on the desired core length. If a single length of plastic tube is to be used, the aluminum tube or plastic tube can be pinned in place. It has been found that not pinning the aluminum tube, but allowing it to project above the brass tube (pl. 1, fig. 1), has certain advantages as mentioned under method of operation. The 12 foot length of aluminum tubing weighs .71 pound per foot or 8.52 pounds for the 12 foot length. In certain types of material a band clamp of stainless steel (15, 25) has been bolted around the phosphorus bronze spring clamps as a safety precaution. The spring clamps have come loose only once, and that was in coring through a heavy oyster reef. In this case, apparently shell fragments pried open the springs. The clamp weighs .27 pound.

This gives a total weight for the double-tube core barrel 12 feet long, in-

[3] Refers to parts shown on the list on pages 267–269.

EXPLANATION OF PLATE 1

FIG. 1.—Charles Aves holding assembled coring tube. This assembly is made up with only a six foot brass barrel (11).

FIG. 2.—Hinged wood block (22) used in removing plastic tube (12) after core is cut and pulled.

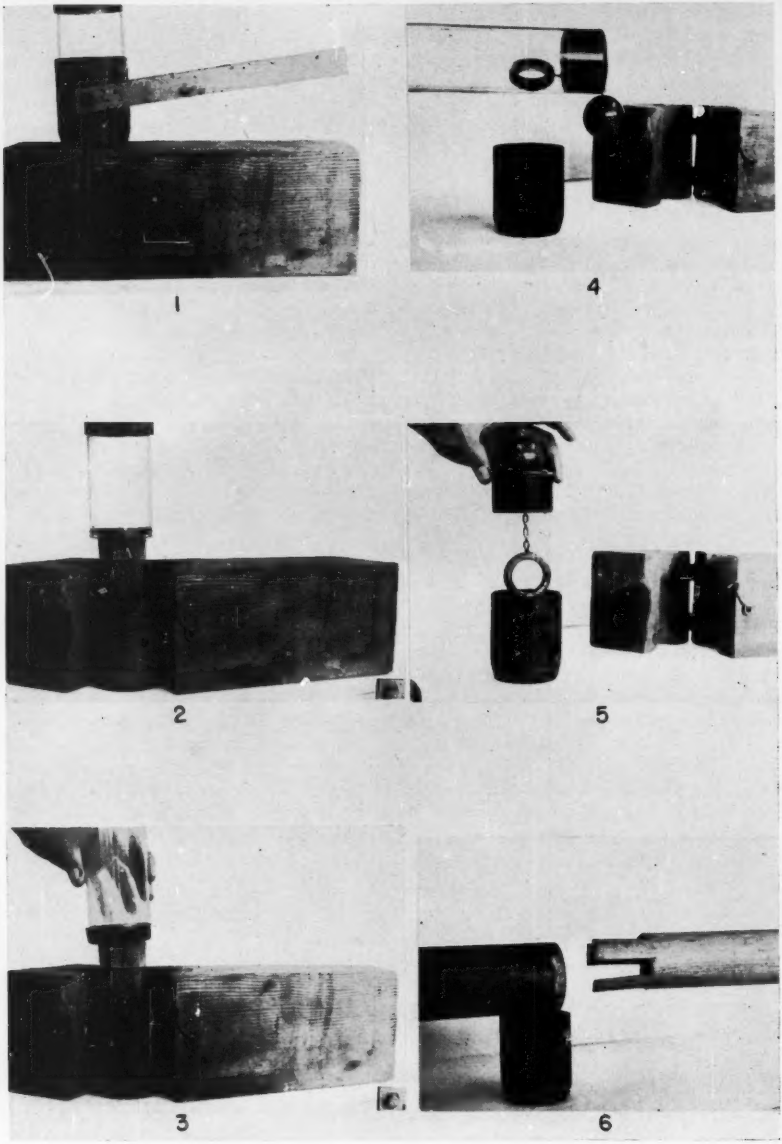
FIG. 3.—Placement of wood piston (21) in wood block (22).

FIG. 4.—Placement of plywood disc (20) on wood piston (21).

FIG. 5.—Closed wood block (22) with wood piston (21) and plywood disc (20) assembled.

FIG. 6.—After core barrel is pulled it is placed on block assembly and plywood disc (20) is placed in the lower end of the plastic tube (12). Note spring (14), steel band (25) and cutter head (19).

FIG. 7.—Steel band (25) has been removed so springs (14) can be released. Spanner wrench (23) is in place.



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cluding the band clamp, of 34.45 pounds when 0.049 inch wall thickness brass tubing is used, or 32.19 pounds when 0.042 inch is used. If a 12 foot core was cut, the barrel would have an additional weight of 60 pounds, plus or minus, depending on the type of material, or a total weight of 90–95 pounds, plus or minus, for a core 12 feet long and $2\frac{3}{4}$ inches in diameter. The writer has cut cores no longer than seven feet, and these were taken from a shrimp trawler where a cabin deck wss available for removing the brass tubing from around the plastic tubing and yet maintaining the core in vertical position. A hoisting arrangement is necessary to hold long cores in a vertical position for removal of the brass tubing. Vertical position is necessary only where the very soft upper end of the core must not be disturbed. For foot work and very shallow water the length of the brass tube can be reduced to demand requirements, with a reduction of weight accordingly.

In certain instances the plastic tubing without the brass tubing shell or cutting head, but with check valve in place, has been used. This is not advised since the plastic tubing is not sufficiently strong to prevent a tendency to collapse when the core is pulled from the clay.

METHOD OF OPERATION

After the core barrel assembly is made up (pl. 1, fig. 1) it is lowered to the bottom. The one precaution is that the aluminum tube is held tight against the plastic tubing so that the plastic tubing does not slip from its seat in the cutter head. This precaution must be taken while the core is being cut. If the core is cut in shallow water it may be pulled by holding the brass tubing, but if it is cut in deep water it can be pulled with the rope. The seated ball valve will prevent the core from slipping. After the core is pulled it is taken from the barrel as shown in the figures of plates 1 and 2.

It is desirable to check depth of penetration against core recovery as soon as the plastic tube is removed from the brass barrel. Short recoveries may result from many factors. Alternating layers of very soft clay and sand may give short clay thicknesses, the evidence of which may be difficult to see in the split core. Striking of shells may cause lack of cutting and incomplete recovery but this cause is usually evident in the split core. These are only two of the many causes. Often the zones where shortening occurred develop unusual texture and structure which may not easily be recognized as induced. By checking penetration against recovery at the time the plastic tube is exposed additional cores can be cut if it seems necessary.

PARTS AND SPECIFICATIONS

1. Rope tied with constrictor knot around $2\frac{1}{2}$ inch O.D. heat treated, hard tempered aluminum tubing. This rope is pulled on to hold aluminum (2) tube against plastic tubing (12) while core is being cut. The

EXPLANATION OF PLATE 2

FIG. 1.—Brass tubing (11) has been lifted from cutter head (19) and plastic tube (12) exposed. At this time water outside the plastic tube will begin to drain out.

FIG. 2.—Wood block (22) is opened and cutter head (19) dropped. Note plywood disc (20) in the lower end of plastic tube (12).

FIG. 3.—Plastic cap is in place on bottom of plastic tube (12) with plywood disc (20) inside. The lower end can be securely sealed with adhesive tape. During the above operations the ball valve (5) remains tightly seated.

FIG. 4.—Ball valve assembly (5, 6, 7, 8, 9, 10 and 13) in place in the upper end of the plastic tube (12).

FIG. 5.—Ball valve assembly as it hangs in the plastic tube.

FIG. 6.—Slotted aluminum pipe (2) which is held firmly against the ball valve assembly. The slots are to allow free passage of water while core is being cut. Brass tubing (11) rests on cutter head (19).

plastic tube can be pinned in position and eliminate the aluminum tube. However, the aluminum tube makes for easy use of different lengths of plastic tubes, and also by holding ropes (1, 4) tight cores can be cut where the water is 10 to 15 feet deep. The author understands that cores have been cut under 35 feet of water with pinned assembly. See plate 1, figure 1, for assembly.

2. Section of 2½ inch O.D. heat treated, hard tempered aluminum tube. This tubing can be secured in 12 foot lengths.
3. Ports cut in 2½ inch O.D. aluminum tubing (2) to allow for free escape of water through ball valve orifice while core is being cut.
4. Rope tied with constrictor knot around 3 inch O.D. hard drawn round brass tubing (11). This is for holding aluminum tube (2) and plastic tube (12) tightly together when lowering assembly in water too deep for brass tube (11) until lowered to position for coring. This rope (4) also is used to pull brass tubing assembly after core is cut.
5. Soft sponge rubber ball which rises above rubber ring (7) when core is being cut but seats against ring when assembly is being pulled from the bottom after core is cut and keeps core from slipping in plastic tube.
6. Brass ring ⅛ inch thick on top of rubber ring of valve (7) assembly which is of the same O.D. size as the plastic tube (12) and sets on the plastic tube in assembly.
7. Soft rubber ring 1½ inches thick, orifice 1½ inches and with O.D. the same as the I.D. of the plastic tube (12).
8. Four brass bolts hold valve seating assembly together.
9. Assembly for connecting soft rubber ball (5) with lead ring (13). The connection between the wire which passes through the ball (5) and the lead ring is a swivel. A small brass bolt keeps the wire from pulling through the ball (5). After considerable use, the ball should be checked to make sure no air or water can bypass along the wire through it, thus permitting undue release of core on ascent.
10. Brass ring with slightly smaller O.D. than the I.D. of the plastic tube (12). Valve seating assembly is placed in top of plastic tube (12). The 4 bolts (8) are tightened and the rubber ring (7) expands radially. The bolts are tightened sufficiently to make the valve seating assembly tight in place but not tight enough to expand or crack the plastic tube (12). This prevents any water escape except through the central orifice which is opened and closed by the soft rubber ball (5). See plate 2, figures 4 and 5, for valve assembly.
11. Three inch O.D. hard drawn round brass tubing with a wall thickness of 0.049 inch. This can be secured in 12 and 14 foot lengths. Similar tubing with a wall thickness of 0.042 inch is available but 0.049 has been used because the plastic tubing has plenty of clearance. Too much clearance allows the plastic tube to change shape when the core assembly is pulled from the bottom. In soft materials the plastic tube will ovate or even collapse if no brass housing is used and render the cores of little value.
12. Plastic tubing with 2¾ inch I.D. This tubing has been supplied in the past in 12 foot lengths by Extruders, Inc., 3232 West El Segundo Blvd., Hawthorne, California. If the tubing is not straight it has been found that it will straighten if the aluminum tube (2) is placed inside and both allowed to warm in the sun. Care must be used to keep oil away from the plastic tubing or it may swell. Plastic tubes can be re-used many times.
13. Lead ring in which a wire loop is anchored when the ring is cast. This

lead ring pulls the soft rubber ball (5) to the valve seat on the top of the rubber ring (7) when the core assembly is pulled after the core is cut.

14. Spring clamp of phosphorus bronze or spring tempered beryllium copper $\frac{3}{4}$ inch wide is sweated to 3 inch O.D. brass tubing (11). See plate 1, figures 6 and 7.
15. Stainless steel band (25, 26) which prevents spring assembly (14, 16, 17) from slipping.
16. Bolt in the spring assembly (14, 17) the head of which fits in the hole in the stainless steel clamp (15, 25, 26) and also holds the plug (17) of the spring assembly which holds the cutter head (19) in place. See plate 1, figure 6.
17. Stainless steel plug sweat onto bolt (16) and phosphorus bronze spring (14) of the spring assembly. This plug fits into a hole in the cutter head (19) and holds the head in place.
18. Two holes in cutter head (19) in which plugs of spanner wrench (24) are inserted to remove cutter head after stainless steel band (15) is removed and spring assembly plugs (17) are lifted from holes in cutter head (19).
19. Marine brass cutter head showing recess for seating three inch O.D. brass tubing (11) and recess for seating $2\frac{3}{4}$ inch I.D. plastic tubing (12). Also position of holes for spring clamp plug (17) and spanner wrench plug (18). The I.D. of the cutting portion of the cutter head is the same or slightly less than the I.D. of the plastic tubing ($2\frac{3}{4}$ inches). A very slight clearance has been found desirable.
20. Disc of paraffin saturated, $\frac{1}{4}$ inch thickness, $2\frac{3}{4}$ inch diameter plywood.
21. Turned wood piston.
22. Hinged 5×5 block of wood through which a hole is bored and in which the piston fits. The coring assembly with aluminum (2) tube tight against the valve assembly is set down over the plywood disc (20). When the cutter head (19) rests on the 5×5 inch wood block the plywood disc will have been pushed into the lower part of the plastic tubing and at the same time the core pushed $\frac{1}{4}$ inch farther into the plastic tubing. The aluminum tube (11) is taken out. The stainless steel band (15) is removed, the spring assembly plugs (17) are lifted and the cutter head (19) held with the spanner wrench by inserting the plugs (24) and standing on the wrench on the block. The brass housing (12) is then raised until the water trapped above the valve assembly and between the plastic tubing (11) and brass tubing (12) drains out. The valve assembly should be covered with water after the core is cut and before it is pulled. If air is locked in the plastic tubing a vacuum will be caused when the core is pulled and some if not all of the core lost. The draining out of the water is desirable when the weather is near freezing since several feet of water may be present above the valve, depending on the depth of water in which the cores are cut. After the water is drained out, the brass tubing (12) is slipped upward and off, the hinged block (22) opened, and the cutting head dropped. A plastic cap is put on the bottom and top and taped. Adhesive tape (waterproof type 1 inch wide) has been found satisfactory.
23. Stainless steel spanner wrench.
24. Stainless steel plugs sweated on spanner wrench (23) and used to remove cutter head (19).
25. One inch wide stainless steel band with two holes to fit over bolt head (16) to clamp spring assembly.
26. Stainless steel bolt to pull stainless steel clamp (25) into position.

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FIGS. 1–2, DECEMBER, 1954

FELDSPATHIZED SHALES FROM MINNESOTA

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ABSTRACT

Three thin beds of brittle shale, one from the Stewartville member of the Galena formation and two from the Dubuque formation, consist predominantly of authigenic orthoclase, with subordinate amounts of hydromica and montmorillonite. These beds are believed to be the product of feldspathization of bentonite derived from volcanic ash.

INTRODUCTION

During a recent study of the Ordovician rocks of southeastern Minnesota (Weiss, 1953) thin beds of brittle feldspathized shale were discovered in the Galena and Dubuque formations. Because they are similar in appearance to the bentonites of the Platteville and Decorah formations, they were at first thought to be bentonites also. To the writer's knowledge these beds have not been correctly identified heretofore.

Authigenic orthoclase in sedimentary rocks is well known (Rosenbusch, 1927; Goldich, 1934; Tester and Atwater, 1934; Gruner, 1936; Gruner and Thiel, 1937; Berg, 1952). Nevertheless, the occurrences described here are of interest for three reasons: the bulk of each rock is authigenic orthoclase; the original material was bentonite; some fossil fragments have been replaced by orthoclase.

The writer is indebted to Drs. S. S. Goldich and Duncan McConnell for aid and advice and for critical reading of the manuscript. Dr. J. W. Gruner made the X-ray analyses of the shales. Dr. Alfred A. Levinson made the X-ray analysis of the clay separate. The photomicrographs were made by Dr. McDonnell. For the chemical analysis made in the Rock Analysis Laboratory at the University of Minnesota, the writer is indebted to Dr. G. M. Schwartz, Director of the Minnesota Geological Survey.

FIELD DESCRIPTION AND STRATIGRAPHY

Within one of the thicker beds of light-gray calcareous shale in the Dubuque formation lies a bed, three to four inches thick, a yellowish-gray to grayish-orange, brittle, feldspathized shale. Because of the color contrast it is plainly visible in outcrop. The lower part of the feldspathized shale is unfossiliferous and poorly laminated, whereas the upper part is thinly laminated and very fossiliferous. The fossils are mostly brachiopods, and although they occur as molds and casts the features are preserved in the most minute detail. Between or penetrating the upper and lower parts of the feldspathized shale bed is a thin streak of soft shale of the same color and composition as the brittle layers. The bed of feldspathized shale has been found at four localities in Fillmore County. At the most southeastern exposure it is 20 feet above the base of the formation and grades evenly downward to only 12 feet above the base in the northwest. Because the Dubuque formation maintains a constant thickness throughout the area studied, the plane of the feldspathized shale is inclined to both boundaries of the formation.

Thirty feet above the base of the Dubuque at Mystery Cave, Spring Valley, Minnesota, is a smooth one-inch bed of hard, very pale orange, feldspathized shale. It is unfossiliferous except for brachiopods plastered to the top of the bed. This bed was not observed at other localities.

A third bed of feldspathized shale occurs in the lower part of the Stewartville member of the Galena formation. It is a pale yellowish-orange, thinly laminated, brittle, mildly calcareous shale with some fossils, mostly graptolites. Because it is nearly the same color as the enclosing dolomitic limestone, it is not immediately apparent in outcrop. Occasional pods of fossiliferous dolomitic limestone which are included in the shale may cause its carbonate content to be as high as 15 percent. The bed is known from three outcrops and one drill hole. Southeastward it is only nine feet above the base of the Stewartville, but rises stratigraphically northwestward to about 20 feet above the base. The base of the Stewartville was defined by Weiss (1953) as the bottom of the yellowish dolomitic limestone above the corrosion zones at the top of the Prosser limestone. This feldspathized shale and the one in the lower Dubuque appear to converge slightly toward the northwest.

PETROGRAPHY

One thin section was made of each of these three rocks. All are so fine grained that a modal analysis, such as that made by Berg (1952) of the feldspathized Franconia sandstone, is impracticable. The mineral percentages are visual estimates.

Lower Dubuque, feldspathized shale: (Sample from Mystery Cave, Spring Valley, Minnesota, SE¼ sec. 19, T. 102 N., R. 12 W.) The shale is an exceedingly fine-grained, homogeneous rock with irregular streaks and blebs of yellowish-brown clay and silt-size, anhedral grains of quartz and feldspar that suggest a primary vitric-crystalline tuff. The grains of quartz and the coarser feldspar grains are concentrated near the base of the bed, suggesting rough sorting during sedimentation. Obscure lamination shows near the base, and the laminae bend around these coarser grains. Some of the larger feldspar grains seem to grade into the microcrystalline feldspar matrix, and therefore may also be authigenic rather than primary. No shards are visible. The matrix consists of exceedingly fine-grained orthoclase, some of which shows crystal faces, and a clay mineral judged by the refractive index to be hydromica. The estimated mineral composition is authigenic orthoclase, 70; hydromica, 20; limonite, 5; quartz, 3; detrital (?) white mica, 2; and garnet, less than one percent.

Upper Dubuque, feldspathized shale: (Sample from Mystery Cave, Spring Valley, Minnesota, SE¼ sec. 19, T. 102 N., R. 12 W.) The gross character of this rock in thin section is much like the one described above. The estimated mineral composition is authigenic orthoclase, 65; calcite, 20; hydromica, 10; quartz, 3; detrital (?) orthoclase, 1; and limonite, 1 percent. Whereas this sample showed about 20 percent calcite the amount probably ranges widely throughout the bed, because a second sample showed only seven percent by solubility test, and the sample examined by X-ray diffraction showed none. Some of the calcite occurs as fossil fragments, some is intimately mixed with the hydromica in irregular blebs and streaks, and some even occurs in areas of the thin section where feldspathization otherwise seems to be complete. Most of the quartz and presumably detrital feldspar grains are corroded, and some of the feldspar grains show a crude zoning from clear to dusty as though impure overgrowths had formed.

Feldspathized shale, Stewartville member, Galena formation: (Outcrop on Bear Creek, SW¼ sec. 35, T. 104 N., R. 13 W., Fillmore County, Minnesota.) This sample is an exceedingly fine-grained rock containing alternating bands of clear to pale-yellow, crystalline material and dark-yellow clay with few distinguishable crystals. Scattered patches of collophane are present; they are almost certainly fragments of graptolites. A few calcareous fragments may have been parts of brachiopods. The thin section does not include any of the fossiliferous dolomitic limestone pods that frequently occur

within this bed. The estimated mineral composition is authigenic orthoclase, 80; hydromica, 10; detrital (?) white mica, 3; collophane, 2; detrital (?) feldspar, 1; calcite, 1; and limonite, 1 percent. Both the collophane and calcite locally show partial replacement by orthoclase (figs. 1, 2).

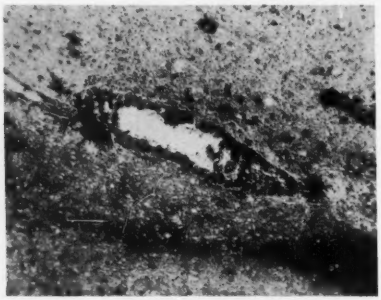

FIG. 1.—Photomicrograph of thin section of feldspathized shale, Stewartville member, Galena formation (described in text). Shows orthoclase replacing a brachiopod shell. Streaks and blebs of hydromica throughout the feldspar cause high opacity. ×50.

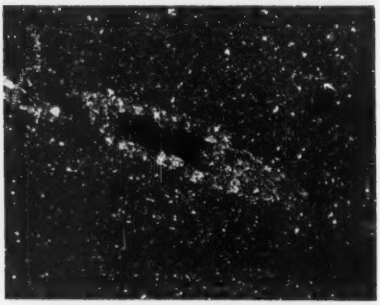

FIG. 2.—Same as Fig. 1, but with Nicols crossed. ×50.

X-RAY DATA

Samples of the feldspathized shales from the Stewartville member and upper Dubuque formation, and of the three parts of the bed in the lower Dubuque were examined by X-ray powder diffraction methods. All samples clearly show the diffraction lines of orthoclase and of quartz in small amounts. Some of the samples from the Stewartville and the lower Dubuque show minor amounts of montmorillonite, and one from the Stewartville clearly shows a small amount of montmorillonite with a slightly reduced layer spacing, suggesting the presence of some illite (Levinson, 1954). An X-ray of a fine-clay separate of the same sample that was analyzed chemically does not show discrete diffraction lines that would suggest a mechanical mixture of hydromica and montmorillonite. A layer spacing larger than that for pure hydromica is indicated, and the material is therefore probably interlayered hydromica and montmorillonite, but mostly the former (Levinson, 1954).

STAIN TEST

A powdered sample of the lower part of the feldspathized shale from the lower Dubuque at Mystery Cave was stained with safranine "Y." Some of the fine-grained material acquired an induced pleochroism, whereas other portions strongly adsorbed the dye without evidence of pleochroism. McConnell (1953) tentatively interprets these results to indicate the presence of hydromica in the former case and montmorillonite in the latter.

COMPOSITION

A chemical analysis of a sample of the lower, unfossiliferous part of the feldspathized shale from the lower Dubuque formation at Mystery Cave, Spring Valley, Minnesota, is given in Table 1. The same sample was studied in thin section, by staining methods, and its fine-clay fraction was investigated by X-ray diffraction methods (see above).

Quantitative determination of the mineral composition of such a rock by microscopic and X-ray diffraction methods is subject to uncertainties. The X-ray diffraction method is relatively insensitive to minor constituents and optical

TABLE 1.—*Chemical analysis of basal part of feldspathized shale bed from 35 feet 10 inches above the underground stream in Mystery Cave. (Eileen H. Oslund, analyst)*

SiO_2	59.96	H_2O+	1.63
Al_2O_3	18.31	H_2O-	1.92
Fe_2O_3	2.55	CO_2	.02
FeO	.07	TiO_2	.22
MgO	1.07	P_2O_5	.07
CaO	.18	MnO	.02
Na_2O	.17	Loss on ignition*	
K_2O	13.25		.28
			99.72

* Loss on ignition minus CO_2 and total H_2O.

study is impaired by the fineness of grain and the similarity of the optical properties of the constituents to be resolved.

Conventional methods for calculating normative minerals are not applicable; nevertheless, the hypothetical mineral composition can be calculated, consonant with the empirical constituents, if certain average compositions for the hypothetical minerals are assumed, as follows:

Orthoclase	16.9% K_2O
Montmorillonite	6.7± H_2O+ (adapted from Ross & Hendricks, 1945)
Hydromica	6.2% K_2O and 7% H_2O+ (adapted from Brindley, 1951)

The water determined at 105°C. is not significant with respect to the structural formula of either montmorillonite or hydromica, but use of the above values permits reduction of the chemical analysis to hypothetical minerals which show reasonable quantitative agreement with estimates made from thin section. The hypothetical mineral composition computed on this basis from the chemical analysis is compared with the mineral composition estimated from thin section in Table 2.

The chemical analysis and hypothetical mineral suite are seen to be in reasonably close agreement with the mineral composition estimated from thin section, with the exception of hydromica and montmorillonite. That the thin section

TABLE 2

Calculated Minerals		*Observed in Thin Section*
Orthoclase	68±10	70
Montmorillonite	14±5	not observed
Hydromica	9±3	20
Quartz	5±2	3
Limonite	3±1	5
Calcite	tr	not observed
White mica	—	2
Garnet	—	1
	99	100

observations were inadequate in this regard is suggested by the stain test, the X-ray results on the bulk samples, and the significant amount of magnesia indicated by chemical analysis. However, the total amount of hypothetical clay minerals closely approximates the amount of clay mineral observed in thin section.

No thorough investigation was attempted, but it is possible that the hydromica and montmorillonite are interlayered. The X-ray diffraction pattern of the fine-clay separate shows a layer spacing somewhat larger than that for the usual hydromica, and suggests interlayered hydromica and montmorillonite (Levinson, 1954). On the other hand, two discrete reactions to the safranine "Y" stain suggest two discrete clay minerals (McConnell, 1953). This paradox does not necessarily refute either of these tests, but indicates the limitations inherent in both methods. These complications are beyond the scope of the present considerations.

CONCLUSION

The high content of authigenic potash feldspar in these shales is striking, but there can be little doubt concerning the authigenic origin. The most plausible interpretation is that the feldspar developed by feldspathization of a potassic bentonite which had a tuffaceous texture and a mineral composition similar to certain Ordovician bentonites described by Weaver (1953a, 1953b).

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JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 24, NO. 4, PP. 275–279
PLS. I–III, FIG. 1, DECEMBER, 1954

OÖLITIC LIMESTONE IN THE TRIASSIC OF VIRGINIA

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ABSTRACT

Oölitic limestone of Manassas (Triassic) age occurs in a quarry near Culpeper, Virginia. Limestones are rare in the Virginia Triassic, and no other oölitic occurrences are known in this area. The major constituent of the rock is primary calcite; whereas illite, chlorite, and talc predominate in the insoluble residue. The heavy minerals as a group appear to be nondiagnostic as to provenance. However, the characteristics of the detrital tourmaline suggest an eastern source. The oölitic limestone apparently represents deposition in a fresh-water lake of limited areal extent. Shallow water deposition is indicated by well developed mudcracks, and minor disconformities within the bed.

INTRODUCTION

The limestone described in this paper is exposed as a thin layer in a sandstone quarry operated by the Virginia Department of Highways along State Route 3, about 3½ miles east of Culpeper and ¼ mile west of Stevensburg, in the north-central part of the Virginia Piedmont.

The most comprehensive report on the Virginia Triassic was written by J. K. Roberts (1928). In this report the bedrock within the quarry is classified as the Manassas sandstone of Upper Triassic (Keuper) age. The Manassas formation is a medium-bedded, fine to dense, deep red sandstone. The red color is due to ferric oxide which occurs disseminated throughout the groundmass and as an envelope around the individual sand grains. In addition to the dominant sandstone there are a few layers of dark-gray to red shales.

Triassic limestones are scarce in the eastern United States, but have been reported from New Jersey (Kindle, 1944; Hawkins, 1951), Connecticut (Davis, 1898; Krynine, 1941), and in the Richmond, Virginia, area (Applegate, 1954). However, specimens from Richmond, Virginia, and South Plainfield, New Jersey, examined by the writers, apparently lack the well-defined oölitic structure of the limestone described in this paper.

The limestone bed or lens described in this paper conforms with the regional structure, striking N. 35°E. and dipping six to seven degrees in a northwesterly direction. The thickness of the bed, which crops out along the eastern face of the quarry, ranges from six to nine inches (pl. 1). The dominant color of the oölitic

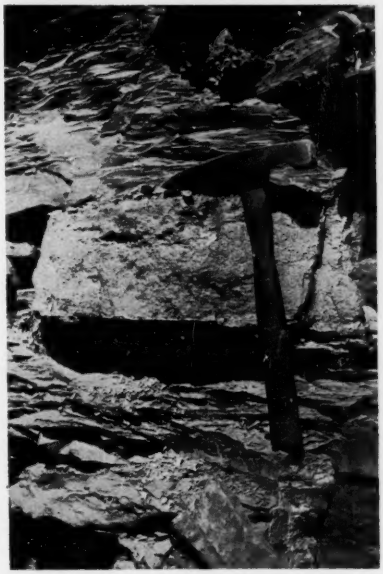

PLATE 1.—The oölitic limestone bed as exposed in the quarry face. The enclosing sediments are thin, gray-green shales.

bed is buff to light-brown with intercalated gray calcareous shale bands.

The purpose of this paper is to discuss the texture and structure, mineralogy, and probable origin of the Culpeper oölitic limestone.

TEXTURE AND STRUCTURE

The texture of the limestone is medium- to coarse-grained, with an uneven fabric. It is composed of individual oölites, averaging about one mm in diameter, and fragments containing many oölites. There is a tendency toward parallelism with respect to the bedding in the flat or disc-shaped fragments. The oölites show a concentric structure of calcium carbonate around minute clay nuclei (pl. 2). None of the oölites studied have a recognizable mineral or fossil nucleus. In fact, not a single fossil was found in any of the material examined.

PLATE 2.—Photomicrograph of a disconformity within the limestone bed. Each such unconformity is marked by a thin layer of clay above the erosion surface and truncation of the underlying oölites. ×42.

Among the most interesting structures noted in the limestone bed are minor unconformities. Four such structures were recognized by the truncation of the underlying oölites (pl. 2). Other minor structures include microfaults, present in many of the larger platy oölites, and small flexures.

MINERALOGY

The major mineral constituent of the Triassic oölite is calcite. Powder X-ray photographs and staining tests show that dolomite is absent. The oölites are very similar to those described by Schoff (1937), who points out that aragonite, because of its instability, alters to calcite with the development of distinct radiating structure. Few of the oölites of the Triassic limestone show more than a suggestion of radial structure, thus it is inferred that the calcium carbonate was precipitated directly as calcite rather than aragonite.

The insoluble components of the limestone were studied in the usual manner, namely, treatment with HCl, bromoform separation, and examination of the light and heavy mineral suites. The limestone bed averages 13 percent residue insoluble in hydrochloric acid. Through bromoform (2.8) separation, the insoluble residue was divided into light and heavy fractions. The light fraction, predomi-

TABLE 1.—*The heavy minerals found in the Triassic limestone, showing relative frequence, shape and form. R=roundness; S=sphericity.*

MINERAL	RELATIVE FREQUENCY			SHAPE		ROUNDNESS—SPHERICITY
	ABUND.	SCARCE	RARE	EUHEDRA	FRAGMENTS	
PYRITE	x			x		
RUTILE		x			x	R.5 S.5
ZIRCON	x			x	x	R.7 S.3
TOURMALINE		x		x	x	R.5 S.3
ILMENITE			x		x	R.3 S.9
CHLORITE			x		x	– –
HEMATITE			x		x	R.3 S.9
GARNET			x		x	R.5 S.9
CORUNDUM?			x		x	R.3 S.9

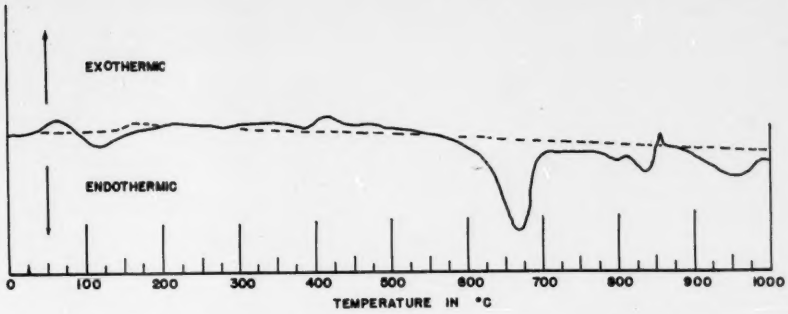

FIG. 1.—Differential thermal analysis curve of the clay-size components of the light fraction.

nantly clay-sized material, was studied with the aid of X-ray diffraction, differential thermal analysis, and the microscope. With the heavy minerals, optical techniques were used for identification.

Several samples of the clay-size fragments of the light fraction were subjected to X-ray analysis. Chlorite, quartz, and small amounts of talc were detected in the samples. Differential thermal analyses (fig. 1) of similar samples identified illite, talc, and a hydrated iron oxide (not limonite).

The minerals composing the heavy fraction are shown in Table 1 with relative frequency, shape, and form. The sphericity-roundness figures were derived by visual comparison (Krumbein and Sloss, 1951).

Among the minerals of this group pyrite is most abundant and occurs only as euhedra and overgrowths. In some instances, pyrite overgrowths have extended from idiomorphic crystals along the concentric structure of the oölites (pl. 3). Because of the mode of occurrence, the pyrite is considered as a post-diagenetic replacement.

The remaining minerals of this suite seem to be definitely detrital, with the exception of authigenic tourmaline. As a group these minerals, except tourmaline, appear to be nondiagnostic as to provenance. For this reason an optical study of the detrital tourmaline was undertaken, following Krynine (1946).

Tourmaline grains, although relatively scarce, were present in all heavy mineral mounts. The individual grains ranged

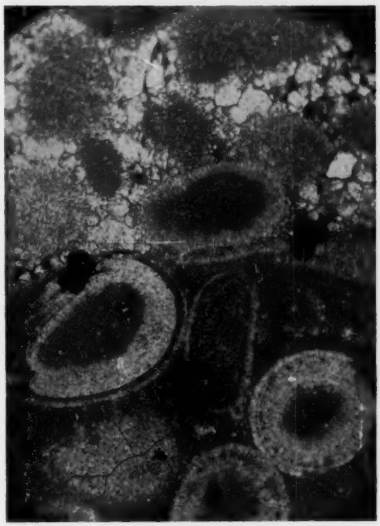

PLATE 3.—Pyrite euhedra (black) replacing oölites and matrix of the Triassic limestone. Note overgrowth extending along the concentric structure of the larger oölite. ×42.

from well-developed singly terminated prisms to highly angular fragments with abraded euhedra predominating. Several prismatic grains were noted with delicate authigenic overgrowths. Such overgrowths were restricted to the pinacoidal face of the euhedra and were elongate parallel to the c-axis. The color of the tourmaline grains was rather constant throughout all samples; differences in shades were due to thickness variations rather than crystal zonation. In nearly all grains, the color ranged from minimum absorption pale blue-brown to maximum absorption deep blue-green with brown tinges. Cavities and inclusions are common. Although several large carbonaceous inclusions were noted, most of the inclusions were not identifiable.

On the basis of these characteristics, the majority of the tourmaline grains from the Triassic oölite may be classified as granitic tourmaline, which, according to Krynine (1946), "formed as an end-phase product within large plutonic igneous bodies." It is almost certain, however, that some of the tourmaline represents the pegmatitic tourmaline and tourmaline from pegmatized injected metamorphic terranes groups of the Krynine classification.

CONCLUSIONS

The exact source of the material comprising the limestone is not known, but it has long been recognized that the constituents of Triassic rocks bear a similarity to the adjacent rocks from which they have been derived. Pegmatitic and granitic terranes, occurring chiefly along the eastern margin of the basin, appear to have supplied the detrital tourmaline identified from the limestone. Roberts (1928) and Brown (1953) have also postulated an eastern source for most of the sediments in the Potomac basin.

The oölitic limestone apparently represents deposition in a fresh water lake of limited areal extent. The fresh water nature of the deposit is indicated by the complete absence of fossils in the limestone, and the presence of plant remains in the sediments of the Potomac basin. Dinosaur footprints are also found in this basin. Shallow water, with oscillations of wave base caused by climatic variation, is indicated by the presence of minor disconformities and well-developed mud cracks.

The following summary gives the probable genesis of the Triassic oölitic limestone:

1. Small pellets of clay from neighboring weathered shales wind rolled into carbonate rich waters.
2. Deposition of calcite around clay nuclei.
3. Lowering of wave-base and formation of mud cracks yielding fragments containing oölites.
4. Raising of wave-base and simultaneous deposition of clay, oölites, and fragments containing oölites.
5. Differential compaction causing minor folding and faulting.
6. Deepening of the basin and deposition of overlying red sandstone.
7. Deposition of secondary quartz in pore spaces and growth of pyrite crystals.

ACKNOWLEDGMENTS

The writers wish to thank C. S. Ross and F. Hildebrand, U. S. Geological Survey, for X-ray analyses and R. T. Martin, Massachusetts Institute of Technology, for differential thermal studies referred to in this paper. C. M. Nevin, Cornell University, J. K. Roberts, University of Virginia, and L. H. Warwick, Division of Geology, read and criticized the manuscript. S. P. Applegate, Richmond, Virginia, furnished samples of the Richmond limestone, and A. C. Hawkins, South Plainfield, New Jersey, supplied specimens of the New Jersey limestone and offered suggestions on the origin of the Culpeper oölitic limestone. The writers are deeply grateful for these services.

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JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 24, NO. 4, PP. 280–282
FIGS. 1–2, DECEMBER, 1954

NOTES

AN OCCURRENCE OF AUTHIGENIC XENOTIME

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Ironstone concretions in the feldspathic sandstone of the late Pre-Cambrian Dripping Springs formation contain small amounts of radioactive xenotime.

The concretions were observed at two localities in the Diamond Butte quadrangle of northern Gila County, Arizona. They were collected for investigation because of their anomalous radioactivity (2 to 4×background). The concretions are shaped like a discus, are five to 12 inches in diameter, and lie parallel to the bedding. The outer portion, or "shell," of the concretions is black in color due to a cement of specular hematite. The xenotime occurs in this hematite-rich portion of the concretions. A sample of concretion "shell" which was analyzed by the Geological Survey Trace Elements Laboratory contained .11 percent equivalent uranium, but only .001 percent uranium. Both uranium and thorium have been reported in xenotime (Dana, 1951).

To concentrate the xenotime the hematite cement was removed from the rock by boiling in dilute hydrochloric acid, and the residue was separated by gravity in thallium formate solution. Through the assistance of Professor Adolf Pabst the xenotime was identified by its X-ray powder pattern. The crystals are irregular in shape, and are no larger than .05 mm in diameter. The optic sign is positive. The optic angle and refractive indices, not measured precisely, are within the range of values previously recorded for xenotime.

The crystals of xenotime occur between the detrital grains of quartz and feldspar, and within the cement of specular hematite and secondary quartz. It has not been found in the inner portion of the concretions, in the rock surrounding the concretions, or in any other rocks of the area. The host strata lie nearly horizontal, have been intruded only by diabase, and are apparently unmetamorphosed and unveined. Specular hematite is abundant throughout the Apache group, and is associated with apatite in at least two localities. The writer believes that iron oxide and phosphates were precipitated from ground water solutions during the cementation of the rock.

[1] The study was made while a graduate student at the University of California, and a pre-doctoral fellow of the Oak Ridge Institute of Nuclear Studies.

FIG. 1.—Cross-section of a xenotime-bearing concretion. The black "shell" is cemented by specular hematite. The xenotime is concentrated in the outer shell of the concretions.

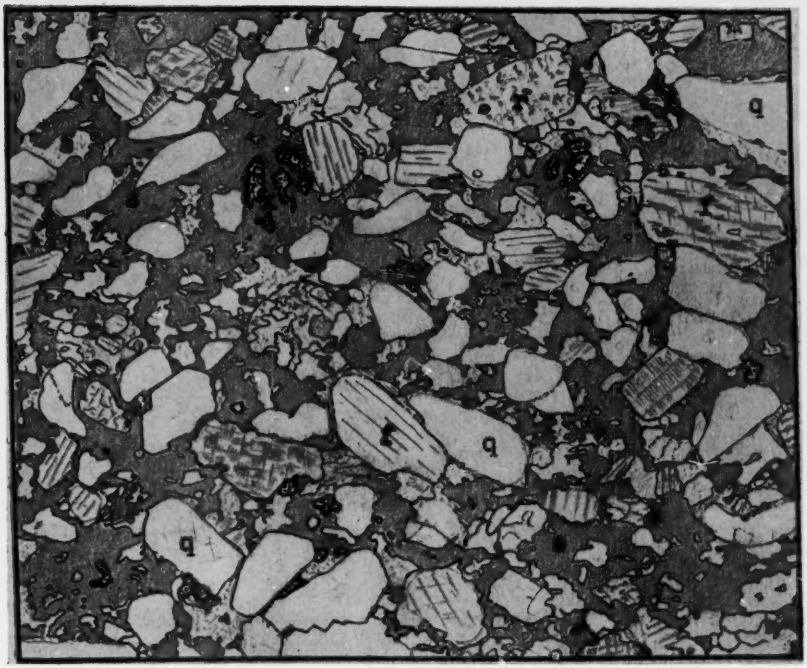

FIG. 2.—A tracing of a photomicrograph of the outer shell of a xenotime-bearing concretion. The sand grains consist of quartz (q), several types of feldspar (f), and a few rock fragments (r). The cement consists of authigenic quartz and feldspar, specular hematite (s), and xenotime (x).

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A COLOR TEST FOR DISTINGUISHING LIMESTONE AND DOLOMITE

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The methods of distinguishing calcitic rocks from dolomitic rocks include staining, effervescence with acids, and optical and chemical analyses. None of these tests are altogether satisfactory for routine use because either they suffer from practical disadvantages or they require special skill and patience. Stains, for example, may soak into pores or become invisible on dark colored rocks, while under field conditions there may be difficulty in sparing sufficient water to wash away the excess. Carrying acid in the field is obviously undesirable and even in the laboratory both acids and stains can make considerable mischief.

A method recently developed by the writer and believed to be original overcomes certain of these troubles without introducing any new hazards. Details of this method, now in use by several oil companies, are as follows:

1. Dissolve $2\frac{1}{2}$ to three grams of anhydrous aluminium chloride and one gram of methyl red in one liter of warm water. The solution is chemically stable and is used at normal room or outside temperatures.
2. Pour two or three drops of the liquid into a small spoon or an evaporating dish and scrape some powder from the rock onto the liquid then stir or shake gently. The volume of liquid to powder should be about two to one.

Calcitic limestone changes the color of the liquid from rose pink to pale yellow in half a minute or less, dolomitic limestone has only a slight effect unless the amount of powder is large relative to the volume of liquid, and dolomite and other rocks, including gypsum and anhydrite, cause no color change at all. Should it be necessary to confirm that the rock is of calcareous type a small area or fragment of the specimen can be strongly heated for a few moments in a bunsen or pressure burner flame prior to crumbling into the liquid. After this heat treatment, dolomite, dolomitic limestone, gypsum, and anhydrite change the color of the liquid to pale yellow as effectively as a limestone, but other rocks remain inactive.

Thus this easily prepared and harmless solution can distinguish reliably between limestones, dolomites, and other rocks regardless of their colors and porosities. The simplicity and rapidity of the method has been found to be of particular value in circumstances such as the examination of a large number of borehole samples. By varying the proportions of liquid and powder the same procedures can also be used to verify the general nature of the cementing medium in sandstones, etc.

Note: In the above text, petrological terms are used in the following ways: Calcitic limestone is rock composed predominantly of the mineral calcite containing within itself from zero to 15 or 16 percent $MgCO_3$. Dolomitic limestone describes rock with a mechanical mixture of carbonate minerals and analysing from 15 to 16 percent to about 40 percent $MgCO_3$ in bulk. Dolomite is rock composed mainly of the mineral dolomite with either a theoretically normal proportion (50 percent) or up to about 10 percent excess $CaCO_3$ in the molecule. These values are molecular percentages.

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DECEMBER, 1954

DISCUSSIONS

SOME REMARKS ON THE ACCUMULATION OF SHELLS IN SEDIMENTS

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In the paper by Powers and Kinsman, "Shell accumulation in underwater sediments and their relation to the thickness of the traction zone" (1953), it should be pointed out that several factors were left out which to the writer appear to be of great importance. To this end the following criticisms are put forth.

Powers and Kinsman have set up the hypothesis that swell is responsible for the accumulation of shell material at specific depths in a sediment. This hypothesis may have some validity. However, it should be pointed out that the errors inherent in the method of sampling far overshadow and complicate the effects, if existant, of sorting due to swell. In fact the sampling method used by them may even preclude the determination of such a process.

The Chesapeake Bay Institute uses a Modified Kullenberg coring device, designed by Silverman and Whaley (1952), for its collection of bottom samples. This apparatus has a moving piston incorporated into it to cause a partial vacuum above the sediment and thereby increases the penetration of the coring tube. The cable for the recovery of the coring gear is attached to the piston. In practice the coring device is dropped over board with the piston in the bottom of the coring tube and the cable slack. When the winch operator feels the coring tube strike bottom he immediately applies the brake on the winch and thereby holds the piston stationary while the coring tube continues to move down. When the coring tube is considered to have stopped moving down, the core tube is brought to the surface by pulling up on the piston until the piston strikes a shoulder in the coring tube and the tube is pulled out of the sediment and aboard ship.

Should the coring gear have a five foot coring tube the piston has to travel five feet from the bottom of the tube to the shoulder at the top before the gear can be pulled up. If, as was often found on the Atlantic shelf sediments, the coring tube only penetrated three feet, the piston still has to travel two feet before it hits the shoulder. This two feet of movement causes an additional vacuum above the sediment and results in flushing the sediment by water on coming above the bottom. This generally disturbed the sediment to such a degree that turbulent motion could be seen within the sediment upon recovery aboard ship.

Calculation of velocities encountered within the coring tube will show that flushing would be more effective than percolation in sorting sediments. The "effectiveness" is dependent upon the amount of piston travel left after sediment penetration ceases and on the amount of cohesiveness in the sediment.

The statement is made on p. 232 that "Laboratory experiments show that agitation of water saturated sands produces vertical sorting." This is exactly what takes place in a core that has been "flushed" on recovery from the bottom.

An examination of cored sediments, reported by Ryan (1953), from Chesapeake Bay shows that a number of cores show shell and gravel accumulation with depth. The majority of cores showing this accumulation, however, are in sediments containing an appreciable amount of silt and clay and displaying stratification. Since most of the Chesapeake Bay sedi-

ments are made up of an appreciable amount of silt and clay they would be highly cohesive and sorting by "flushing" would not be expected.

Cores taken in clays did not show this effect of disturbance except along the walls of the core liner where the outer edges of the core were disturbed. It sometimes happened that these compacted muds (or clays) were sucked up into the upper portions of the core liner en masse.

As to the effectiveness of "hydraulic lift" (p. 231) caused by velocity gradients, the work of White (1940) should be cited. White has shown that a particle only three percent of the weight of an ordinary silica grain of the same diameter (5.6 mm) did not lift by a velocity gradient (where theoretically the hydraulic lift increases with increase in size) even at high velocities.

The schematic representation of the probable relation between traction zone thickness and water depth in figure 5 bears a little discussion also. Absolute scales are not given so we will have to derive values for the two scales from the text. "The range of available depths . . . is about 25 feet. The mid point of the range is a depth of about 95 feet. The range of data in relation to the expected function is indicated by the interval BC in figure 5." This gives us an idea of the depths from which the samples were taken; i.e., from about 83 feet at B to 107 feet at C. Now for the scale of traction zone thickness: if we assume from the statement on p. 230 that six feet is the thickest traction zone found from B to C we then have some scale for point B. Extending this height to the left we have a scale (or unit) which can be multiplied up the ordinate. This would show that Powers and Kinsman would expect a traction zone thickness at A (the end of the seaward extension of the breaker zone) to be *30 feet*. If, on the other hand, we assume that the trend in grain size versus traction zone thickness of figure 4 is correlative with the curve from B to C of figure 5 and then choose the *minimum* traction zone thickness on the high side of the trend we have for our basic unit height at B (fig. 5) a thickness of 3.5 feet. This would then give a thickness of *17.5 feet* for the traction zone at A.

Putnam (1949), in the development of wave energy dissipation by percolation, assumed *no* movement in the sediment on the sea bottom. He states "The assumption that sand does not move at the sea bottom is valid for the major portion of the region of interest. However, in the vicinity of the breakers sand has been observed to be in motion in many instances and is probably due to water percolation from the uprush portion of the surf." In an earlier discussion (Putnam and Johnson, 1949) it is stated that the *maximum possible* value for the velocity of flow in percolation, *calculated from theory*, indicates a magnitude of 10^{-3} ft./sec. The diameter of a particle that this velocity would *just* support can be calculated from Stokes' law. Carrying this calculation out (using the density and viscosity of normal sea water at 15° C) results in a diameter of 0.0205 mm. This diameter is about the diameter of the midsize grade from 1/32 to 1/64 mm. or 5.5 ϕ. This means that only particles smaller than this diameter in the *very topmost* layer of the sediment would move; that is, smaller than fine silt.

Considering these criticisms it would seem advisable that a very careful analysis be made before the validity of the hypothesis can be established. The effect reported may only be due to sampling method.

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ANNOUNCEMENTS

SOCIETY OF ECONOMIC PALEONTOLOGISTS AND MINERALOGISTS ANNOUNCEMENT OF 29TH ANNUAL MEETING, NEW YORK MARCH 28–31, 1955

The 29th Annual Meeting of the Society of Economic Paleontologists and Mineralogists will be held next March 28–31, 1955, in New York, N. Y. The meeting will be held, as usual, jointly with the American Association of Petroleum Geologists and the Society of Exploration Geophysicists. The headquarters hotel is the Statler.

There will be one joint session with A.A.P.G., one session of paleontologic papers, one session of mineralogic papers, one general session, and two symposia.

BROOKS F. ELLIS, American Museum Natural History, New York, is S.E.P.M. General Chairman for New York, E. C. DAPPLES, Northwestern University, Evanston, is Chairman of Research Committee in charge of symposium on problems of sedimentation in barred basins, W. S. HOFFMEISTER, Carter Oil Company, Tulsa, is chairman symposium of pollen, spores and related materials, M. L. THOMPSON, University of Kansas, Lawrence, is chairman paleontological session, R. R. SHROCK, Massachusetts Institute of Technology, Cambridge, is chairman mineralogical session.

FOURTH INTERNATIONAL CONGRESS OF SEDIMENTOLOGY

The fourth meeting of the International Union of Sedimentologists was held at Göttingen, Germany, from July 9 to 15, 1954. At the third meeting of this Union, at Wageningen, Holland, in 1951, an invitation was received to hold the fourth meeting at the Shalling Laboratory, Esbjerg, Denmark (*Journal of Sedimentary Petrology*, v. 21, 239–241) but various difficulties arose which caused its transfer, at the invitation of Prof. C. W. Correns, to the Mineralogisches Institut der Universität in Göttingen.

The meeting was attended by about 140 scientists from 14 countries: Germany, France, Denmark, Holland, Belgium, England, Sweden, Switzerland, Spain, Italy, the United States, Canada, Russia, and Japan. Germany and France contributed over 70 per cent of those participating.

There were about 35 papers presented during three and one-half days of meeting, and of these only two were in English. Excursions to various parts of the Western Zone of Germany occupied two days prior to the Congress and two and one-half days during and at the end of the Congress. Members of the pre-session field excursion assembled in Braunschweig on July 7 and saw various rock formations, soils, glacial sediments, dunes etc., in the vicinity of Braunschweig, and on the next day saw the geology enroute to Göttingen. Other excursions were made in the country near Göttingen upper Buntsandstein, Muschelkalk, Middle Keuper red clay which contains the recently described clay mineral, corrensite (see Heidelberger Beitrage z. Min. u. Petr., Bd. 4, 1954, 130–134)]; in the Harz Mountains [Grauwacke, Kieselschiefer, Kupferschiefer, Zechstein-Kalk, Zechstein-Gips (worked for gypsum), Zechstein-dolomit)]; to the potash salt deposts in the Werra province south of Göttingen, which included a visit to the underground workings, and a quick look at metalliferous mining in the Kupferschiefer.

The papers presented dealt with many aspects of sedimentation and sedimentary rocks. Included were: studies of deposition in basins, deltas, estuaries, beaches, dunes, deep-sea deposits, and salt deposits; the structures of sedimentary rocks; diagenesis and mineral development in sedimentary rocks; secondary alteration;

continental deposition; heavy-mineral distribution and provenance; quantitative analysis of rock composition by X-ray analysis; glacial and post-glacial sediments; recognition of traces of life in sediments. All the papers are to be published in a special number of the Geologische Rundschau of which Prof. Roland Brinkmann is undertaking the editorial work and all manuscripts should be sent to him. Fifty reprints will be given free to authors, and members of the Union will be able to buy the whole volume at a reduced rate.

A business meeting was held at the end of the Congress, and at this it was reported that the President, Dr. D. J. Doeglas, had resigned. No new president was elected, nor was any change made in the original committee. Dr. Andre Vatan continues as secretary. He asked all present at the Congress to fill in a membership form and a bibliographic form to enable him to keep a register of sedimentologists. The subscription is one dollar ($1) per year, payable by international money order. The address is: Association Internationale de Sedimentologie, Institute Français Petrole, Rueil (S. et O.), France.

Dr. Vatan asked also that a representative of each country that produces oil make a brief report on the use of sedimentary petrology in the oil industry, so that a report can be prepared for presentation at the Petroleum Congress to be held June 6–15, 1955, in Rome, Italy. Dr. C. M. Gilbert, University of California at Berkeley, offered to prepare a report for the United States.

It was decided to hold the next meeting in 1958 in Copenhagen at the invitation of Dr. K. Hansen. Prof. A. Lombard, Brussels, extended an invitation to the Congress to hold this next meeting in Belgium, if Denmark should again find difficulty in making arrangements in 1958. The Congress closed with a hearty vote of thanks to Prof. Correns and his associates for the very interesting and enjoyable meeting which had been arranged.

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REVIEW

Principles of Geomorphology, by W. D. Thornbury, 1954. Pp. ix+618; figs. 268; 6×8½ ins., cloth. John Wiley & Sons, Inc., New York. Price, $8.00.

Why review a geomorphology text in the *Journal of Sedimentary Petrology*? The answer is that a good text in any branch of geology contains worthwhile information on the margins of the other specialties. And Mr. Thornbury's book is a good text.

Most textbooks of geomorphology are limited to detailed description and classification of land forms. This book is the exception. The first eight chapters deal with the background of geomorphology, the concepts of dynamic geologic processes, climatic modification of these processes, the importance of lithologic and structural controls, the sequence, duration, and interruption of processes, and the net results of all these factors. Chapters 9 through 20 deal with specific land forms such as "Topography upon Faulted Structures," "Karst Topography," "Mountain Glaciation," and "Land Forms Resulting from Volcanism." Mr. Thornbury has not systematized these descriptive chapters by process, lithology, structure, or climate alone, but has chosen to discuss each major land form type *per se*. The genetic relationship of the various types is cleverly woven into each chapter. This makes the book a bit hard to use for reference, since a specific process or concept may be discussed at several widely separated places in the book. The last two chapters discuss the tools available to the geomorphologist and practical applications of geomorphology. Here again the book makes a very constructive departure from earlier geomorphology texts.

Mr. Thornbury's discussion of the epigene processes—both degradation by weathering, mass wasting and erosive action of water, wind and glaciers; and aggradation by water, wind, and glaciers—is a good summation of important processes in the formation of sediments. His coverage of epigene constructional forms is also useful to the stratigrapher wrestling with the problems of horizontal and vertical boundaries of a particular lithofacies unit.

Regardless of your specialty in geology, you won't go wrong to read Mr. Thornbury's *Principles of Geomorphology*.

R. W. DECKER
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Journal of Sedimentary Petrology

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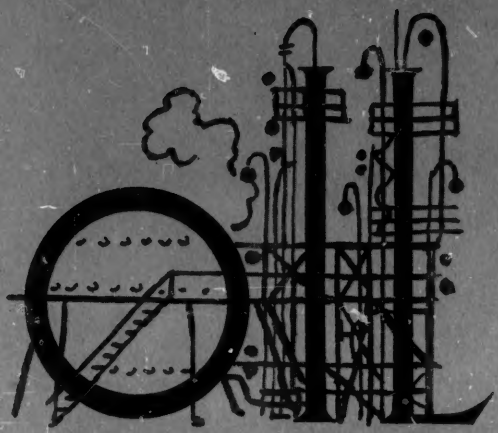

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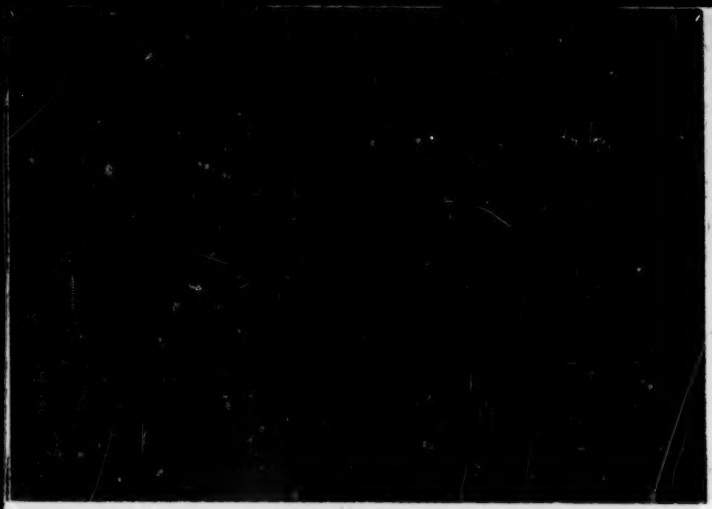

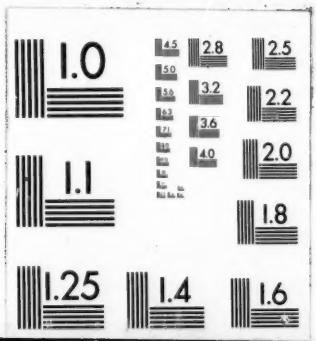
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